International Journal of Science and Mathematics Education (2021) 19:881–897
https://doi.org/10.1007/s10763-020-10103-8

Exploring the Challenges and Enablers of Implementing a STEM Project-Based Learning Programme in a Diverse Junior Secondary Context

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Received: 9 January 2020 / Accepted: 11 May 2020 / Published online: 10 June 2020

Abstract
In the rush to implement STEM programmes in economically disadvantaged school districts, there is a pressing need to develop a stronger sense of what might be considered effective and appropriate STEM practices for diverse students. The aim of this study was to characterise the experience of implementing an integrated STEM Project-Based Learning (PBL) programme in an Australian secondary school located within a diverse, socio-economically disadvantaged community. To identify enablers and constraints in delivering STEM PBL in this context, the study utilised qualitative data from interviews with school teachers and leaders, school planning documents and an extended series of classroom observations. Key findings point towards the importance of building a school culture that supports innovative pedagogy; the need to purposefully scaffold the capabilities of teachers and students to engage with active learning; and the potential value of multi-dimensional assessment allowing students to demonstrate STEM proficiency through novel forms of evidence.

Keywords Interdisciplinary instruction · Project-based learning · Secondary education · STEM education

There is considerable disparity in the educational outcomes of diverse student groups in Australia. International testing of student performance in science and mathematics has consistently linked these disparities to socio-economic status (SES), Indigeneity and geographic location (Organisation for Economic Cooperation and Development [OECD], 2016). In many developed nations, including Australia, gaps in learning outcomes between minority and majority groups may be equivalent to several years of schooling (UNICEF, 2018). This inequity has remained largely unchanged over time

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(Thomson, De Bortoli & Underwood, 2017) and motivates inquiry into how the ubiquitous STEM innovation agenda is conceptualised to ensure diverse students are not left further behind. It is critical that students experiencing disadvantage are exposed to quality STEM education in order to safeguard their access to the affordances of this domain and to ensure they are provided opportunities to develop as critical and creative thinkers. Previous research in the Australian context has shown that given the opportunity, disadvantaged students show great capacity to work scientifically and innovatively (Dawson & Carson, 2020; Wilson & Stemp, 2010; Wilson & Boldeman, 2012; Wilson & Alloway, 2013).

STEM as an Educational Priority

International efforts to increase the prominence of STEM education across all educational sectors have been driven by declining student enrolments in STEM-related subject areas, enhancing economic productivity and preparing students for the future world of work (Marginson, Tytler, Freeman & Roberts, 2013). In the Australian context, the federal government's National STEM School Education Strategy includes five key areas for national action: (a) increasing teacher capacity in STEM; (b) increasing student knowledge, participation and understanding of STEM; (c) encouraging school system support for STEM education initiatives; (d) facilitating effective partnerships; (e) building a strong evidence base (Education Council, 2015). In alignment with this over-arching national strategy, individual Australian states and territories have implemented a range of policies and programmes to enable STEM education across schooling systems and to work towards national priorities (see, for example, Queensland Government, 2016).

Notwithstanding intention, there is evidence that the Australian education system is not yet providing comprehensive and equitable STEM education (Timms, Moyle, Weldon & Mitchell, 2018). Constraining factors include the under-preparedness of the teaching workforce and a national curriculum that is packaged in discrete disciplines and considered by some to be not 'future-facing' (Timms et al., 2018). In the case of schools serving socio-economically disadvantaged communities, insufficient time, staff and other resources often limit the effectiveness of STEM programmes (Lowrie, Downes & Leonard, 2017). In addition, Australian educators lack a localised evidence base to guide STEM initiatives, resulting in a scattergun approach to programme implementation and teaching practices. While hundreds of STEM programmes are currently underway in educational jurisdictions across Australia (Lowrie et al., 2017), there is a pressing need to identify effective and appropriate STEM practices to meet the needs of all students.

Inclusive STEM Education

As noted by English (2017), navigating current STEM agendas is complex and 'suggesting approaches to advancing STEM education is even more difficult' (p. 6). It is beyond the scope of this paper to address the myriad definitions and forms of STEM education, with the intent being rather to highlight in broad terms effective practices for inclusive STEM education. A growing body of international work in this area is beginning to make sense of how diverse students and communities might be supported to succeed in STEM contexts. In a large-scale study of 20 US schools, LaForce, Noble, King, Century, Blackwell, Holt, Ibrahim et al. (2016) identified 76 critical components of inclusive STEM education, as well as a theoretical framework representing goals and strategies common among the schools in their study, namely, personalisation of learning; problem-based learning, rigorous learning; career, technology and life skills; school community and belonging; external community; staff foundations; and external factors. Critically, the authors found that in catering for students with diverse needs, schools did not narrow their conceptualisations of STEM education to focus on particular disciplines. Rather, their approaches were anchored in rich pedagogical practices (such as problem-based and student-centred learning), developing engaged and autonomous learners, and prioritising relevance and real-world connections. STEM education was thus seen less as a means of channelling students into a STEM career pipeline, and more as a vehicle for creating well-rounded citizens able to critically engage the world around them, with a constructivist pedagogical orientation underpinning the development of students as 'critical thinkers and active citizens' (p. 9).

Peters-Burton, Lynch, Behrend and Means (2014) identified critical components of inclusive STEM schools that align with the findings of LaForce et al. (2016), highlighting the importance of active learning strategies such as problem-based learning, connection to the real world and rigorous learning experiences. In addition, Peters-Burton et al. (2014) draw attention to the importance of blending formal and informal learning experiences in STEM, having well-prepared staff and supporting under-represented students (e.g. through bridging and tutoring programmes). The authors note that inclusive STEM schools 'do more than focus on STEM or use new technologies…rather, they create new *opportunity structures* for their students' (Peters-Burton et al., 2014, p. 66). The creation of opportunity structures incorporates notions of social capital (Peters-Burton et al., 2014), which may be understood as the formation of networks of relationships cooperating in pursuit of the common good (Stevens, 2005). For students in under-represented groups, social capital involves an extended web of relationships that afford young people the agency to realise their full potential (Wilson & Stemp, 2010). In the context of STEM education, opportunity structures may be embedded in an emerging global STEM commons (Marshall, 2009).

Project-Based Learning in STEM Education

A significant attribute of inclusive STEM schools is the attention to instructional practices to engage students in deep learning. Marshall (2009) provides a rich definition of deep learning that incorporates commonly cited desirable characteristics of STEM education, such as the fostering of critical and creative thinking capabilities:

> *Deep learning* is holistic, inclusive, and relational. It is rooted in the awareness that it is often through the integration of polarities, paradoxes, and seemingly disparate ways of knowing that genuine understanding, creativity, innovation, and wisdom can emerge. Deep learning is both active and reflective. By immersing learners in the complexity and challenge of consequential real-world problems and meaningfully engaging them in the big ideas, questions and ambiguities

> of the human experience, deep experiential learning can transform their thinking. It can reignite their passion and insatiable curiosity and weave a tapestry of connection that grounds their learning in the roots of personal meaning and purpose. (p. 50)

The vehicle for encouraging this type of experiential, connected and authentic learning in the context of STEM education is often problem- or project-based learning (English, 2017). Both approaches involve presenting students with open-ended, real-world problems that potentially have multiple solutions (Lowrie et al., 2017). The difference between problem- and project-based learning is primarily a matter of scale—problem-based learning activities tend to be of shorter duration, whereas project-based learning activities occur over an extended period of time (e.g. a full academic term). In the context of STEM education, project-based learning is often preferred in that the extended timeframe allows for a more in-depth and authentic exploration of complex issues comprising multiple embedded problems (Capraro & Slough, 2013).

Capraro and Slough (2013) formally define STEM Project-Based Learning (PBL) as 'an ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems which when considered in their entirety showcase student mastery of several concepts of various STEM subjects' (p. 2). STEM PBL is seen as a special form of inquiry characterised by the design of learning environments that make content accessible and thinking visible; help students learn from others; and promote autonomy and lifelong learning (Slough & Milam, 2013). STEM PBL is seen as particularly advantageous for diverse learners due to the expansive nature of project work, which allows for differentiation and tailoring of tasks to the strengths of students with a range of academic capabilities (Capraro & Slough, 2013).

PBL involves a delicate balance whereby the teacher must provide sufficient scaffolding for students to develop subject and practical expertise, while maintaining the distance they require to develop as autonomous learners (Slough & Milam, 2013). Successful PBL requires thorough planning to ensure students are appropriately supported to meet learning objectives (Bell, 2010). Typical pedagogical activities undertaken by teachers within PBL include the development of a significant, contextually relevant project (that aligns with curriculum standards), building a culture to promote student independence and growth, managing project activities, scaffolding student learning, devising authentic assessment to measure student learning and engagement to ensure students maintain motivation and produce quality learning artefacts (Larmer, Bergendoller & Boss, 2015). Students, for their part, are involved in collaborative brainstorming, researching, devising solutions, reflecting on feedback, prototyping, creating and building, and presenting solutions to an appropriate audience (Bender, 2012).

While PBL is often hailed as the solution to ensure students develop twenty-first century skills (Bender, 2012), successful PBL is not without its challenges—particularly in the context of secondary education. STEM PBL presumes integration across the various STEM disciplines, which requires alternatives to the siloing of subject areas typical of mainstream secondary educational settings (Shernoff, Sinha, Bressler & Ginsburg, 2017). In addition, the pedagogical repertoire associated with thematically unified units and projects, which draws from multiple curricular areas, is more commonly supported in the training of elementary/primary educators than secondary teachers. Secondary educators tend to receive training in one or two discipline areas and may feel under-prepared to teach across the breadth of STEM (Shernoff et al., 2017). As noted by English (2016), research in the area of integrated STEM education is in its infancy; there is currently little guidance on best practices in secondary education. The present study aimed to address this gap by capturing the experiences of teachers and school administrators in the implementation of integrated STEM PBL in a secondary school serving a socio-economically disadvantaged community. Specifically, the research aimed to identify the enablers and constraints to delivery of STEM PBL for junior secondary students in a context of socio-economic disadvantage.

Method

As a descriptive case study, this project was methodologically embedded in the qualitative research paradigm. Case-study inquiry was seen as particularly well-suited to the project due to its emphasis on the development of a 'humanistic, holistic understanding of complex situations' (Brown, 2008, p. 10). Factors unique to teachers engaging with vulnerable young people in low-SES schooling contexts necessitate a research strategy that situates teaching praxis within its underpinning conditions. A case-study approach was the most amenable to producing a credible account of the practices of teachers with respect to its emphasis on the investigation of 'a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident' (Yin, 2009, p. 18). Case-study inquiry is embodied through an evolving design that unfolds in pursuit of an in-depth understanding of the phenomena of interest (Merriam, 1988)—in this case, the experiences of teaching and learning within an emerging integrated STEM PBL model in a low-SES school setting.

Research Context

The local government area (LGA) central to this study was suburban, forming part of metropolitan South-East Queensland. The LGA had a higher rate of multicultural diversity than Queensland more broadly, with over a quarter of residents born overseas (Australian Bureau of Statistics [ABS], 2016). The school of the case study—a large secondary school with over 2500 students—had an Index of Community Socio-educational Advantage (ICSEA) score of 945, indicating a high degree of community disadvantage relative to the Australian average. Fifty-one percent of students were located within the bottom economic decile of family income, and 36% of students had a language background other than English (Australian Curriculum and Reporting Authority [ACARA], 2019). The school was selected for the study based on its diverse and economically disadvantaged student cohort and widely recognised excellence in teaching and leadership. Further, the school has been considered a hub for innovative approaches to STEM teaching and was recently shortlisted as a finalist for a national STEM award. Study participants included both the Science and Information Technology Heads of Department (HoDs), who indicated an initial interest in the project, and six teachers working across the junior secondary STEM initiatives who volunteered to contribute to the research. Participants' teaching experience ranged from 2 to 16 years. Pseudonyms have been used to protect the anonymity of the school and participants.

Data Collection

The school was invited to participate upon receipt of human research ethics approval. Data for the project was formally collected over the course of two 10-week school terms in the latter half of the 2019 school year. The researcher reviewed publicly accessible school documentation, along with internal curriculum planning documents provided by the participants. Sixty-minute semi-structured interviews were conducted with a thematic focus on:

- teachers' own background, interests and personal definitions of STEM education;
- aspirations for student learning and skill development in STEM education;
- enablers and constraints for delivering STEM education in their particular schooling context;
- supports required to strengthen delivery of STEM education

Weekly classroom observations took place over the course of 8 weeks, guided by a protocol developed to reflect Patton's (1980) key areas of observational interest, namely, the physical setting, social climate, programme activities and participant behaviours, informal interactions and unplanned activities, language, non-verbal communication and programme documents. In total, 28 × 70-min lessons were observed, totalling 1960 min. The researcher also engaged in lunchtime interactions with teaching staff and informal conversations before and after lesson observations.

Data Analysis

Research data included notes on classroom observations, transcripts from semi-structured interviews conducted with teaching and leadership staff, and selected organisational, policy and curriculum planning documents. Qualitative analysis of this data occurred through a process of coding and progressive focusing (Simons, 2009). First, a preliminary inductive analysis of interviews and the researcher's field observation notes was undertaken to identify major themes and outline a protocol for the systematic coding of data. Nvivo10 qualitative analysis software (QSR International) was then used to code all interview transcripts in accordance with this protocol. Verification strategies included triangulation of data across multiple data sources and member-checking the authenticity of data representation with study participants. Extended engagement with the study site, including observations across a wide range of lessons, further enhanced the credibility of study findings (Creswell, 2013).

Findings

The intent of the study was to explore an emerging STEM PBL programme in a highly diverse schooling context, with an analytical focus on identifying the enablers and challenges to successful implementation of an inclusive STEM PBL programme. Reflecting upon data from multiple sources, three over-arching themes were identified that resonate with the key tenets of STEM PBL theory and provide an umbrella for exploring the possibilities and pitfalls of innovation among low-SES schools in this space, including:

1. Building the Culture;
2. Promoting Active Learning;
3. Multi-Dimensional Assessment.

These themes are explored in the following sections.

Theme 1: Building the Culture

According to Larmer et al. (2015), 'alignment to mission, vision and values is all important when assessing a school system's readiness for PBL' (p. 133). Key to programme success is an alignment of the school's values and vision with the student-centred learning and professional collaboration at the heart of STEM PBL (Larmer et al., 2015). For schools in low-SES communities, who often experience poor standardised test results and associated pressure to focus more on literacy and numeracy 'basics', it can be challenging to promote a more innovative and engaging learning environment. In the case of Wattle State High School, significant effort has been dedicated to enhancing the school's reputation amidst the socio-economic disadvantage of the local community:

> Wattle State High School never used to have a very good reputation at all, but it does have a very good reputation now. There's actually nothing wrong with living in Wattle, however there are pockets—like anywhere—that there's an issue. So it's just getting that mentality out of these kids, that they can be better and do better. They've just got to give it a go. (Angela, Science HoD)

Transforming the reputation and value orientation of the school has been enabled by creating a culture of high expectations with a focus on excellence across academic, sporting, cultural and creative endeavours. School policy, reporting and curricular documents reflected a language of passion, possibilities and pride in the school community. This language also manifested in teachers' identification of their school's unique attributes:

> I love that there's so many opportunities in this school—that students are able to find something they enjoy. I think my experience of high school was very different in that there were only a few options. I just see that there's so many opportunities here that kids can actually find something that they enjoy and that they want to do, and that teachers are willing to put in the extra mile to help those students succeed in whatever they find their passion is. (Amy, Teacher)

The school purposefully employed a large number of new teaching graduates, which contributed to a sense of energy and renewal. Overall, teaching staff demonstrated a great deal of pride in their school and viewed their diverse student cohort as an asset that strengthened the cultural fabric of the school:

> It's a great school. I think the culture here is very unique. We have students from all walks of life here, and they bring a spark of life into the classroom. I love watching particularly our Pacifica students bring their cultural diversity into performances and into the classroom. (Brad, Teacher)
> The kids, themselves, are the culture of the school; it's very community-based and very connected. And it's unique in that we are in a low-socioeconomic area but we are such a large school, we provide such a lot of opportunities for our students, that we are definitely different to other schools in this same area. We're one of the largest schools with the lowest ICSEA rating. (Angela, Science HoD)

This orientation towards celebrating the strengths of a diverse student population and centring student needs at the heart of curriculum and pedagogical decision-making, laid a fertile ground for implementation of a STEM PBL programme. Teaching staff considered STEM as a vehicle to open new pathways and opportunities for students, as well as a means for developing students' essential twenty-first century skills and competencies—an increasing focus of the school.

> The school philosophy is dedicated to developing students and extending them, preparing them for the real world and future education. And I think STEM education does all of that. And especially in this kind of era, it's preparing the students for the jobs that are going to exist that may not yet. It's so important that they see the value in STEM so that they are prepared when they leave school and there's other opportunities for them (Amy, Teacher)

In line with its clear intent to broaden students' horizons and learning opportunities, the school had recently moved away from the scripted curriculum provided by the state and instead granted teaching staff the professional freedom to innovate with their pedagogy—an essential precursor of successful STEM PBL.

> There's a willingness to experiment, to trial and do different things. (Steve, IT HoD)
> Admin are quite happy for us to give anything a go and see if the kids are interested. And they are all very driven by what's going to engage the students. (Angela, Science HoD)
> We are given freedom with how we teach our lessons as long as we are hitting the topics that align with the Australian Curriculum. (Tim, Teacher)

Teachers' receptiveness to new pedagogies was strengthened by allowing teaching staff to self-select into initiatives such as the STEM PBL programme, rather than being corralled or coerced. This mitigated potential challenges with respect to the fact that many of the teachers in the STEM PBL programme were 'out-of-field'—only one member of the teaching staff at the time had a professional background in STEM. Staff participation was thus primarily driven by internal motivation and personal interest.

> When I got my job here, I was employed as a Maths/Science teacher, because there were no PE (*Physical Education*) positions available. And then from there I developed an interest in robotics and technology…more from a hobby perspective. Things that are designed quite well—I appreciate that type of thing. I like to know how things work. (Tim, Teacher)

Recognition of the time and space needed for plan and collaborate effective STEM PBL units also proved essential in ensuring teacher buy-in. School leadership staff were aware that teaching staff engaging with the programme for the first time required significant planning time and support to transform their pedagogical practice. Carving out time for teachers to come together and collaboratively plan was seen to be a challenging but necessary component of building and sustaining an effective integrated STEM PBL programme:

> Being new assessment, being new ways of learning, new topics, figuring out that clear kind of end goal and also working out the steps in between…working out how to support the students to actually get there in the end. I just found that we did spend for semester one—the four teachers that I taught with—a lot of time in that pre-planning stage, which was great because we were provided with that time. (Chloe, Teacher)

Teachers noted, however, that creating collaborative communicative structures in a secondary setting, where it is more common for teachers to stay within their disciplinary teams, was a difficulty requiring ongoing attention:

> Sometimes we did not communicate so well. And facilitating that communication within ourselves during term time was a challenge, so I guess it's important to practice working collaboratively as teachers before you make the kids work collaboratively. (Amy, Teacher)

Theme 2: Promoting Active Learning

The principle of 'active learning' is grounded in the constructivist tradition and is broadly understood as any approach to instruction that encourages active rather than passive engagement in learning (Siraeva, 2018). Barnes (1989) proffers a deeper conceptualisation of active learning that highlights the importance of meaningful and relevant learning tasks, connected to real-world contexts, that provide students opportunities to negotiate goals and methods of learning, as well as supporting the development of higher-order thinking skills such as critical evaluation and reflection. In the context of Wattle State High School, active learning was widely promoted to both teaching staff and students, with classroom posters detailing what it means to be an active learner:

> Be open to different ideas and ways of thinking.
> Ask questions and seek feedback on your learning inside and outside of the classroom.
> Actively participate by sharing your thoughts, ideas and listening to others (WSHS Poster excerpt)

The school's STEM PBL programme incorporated principles of active learning design through the creation of semester-long projects with a focus on critical and creative thinking. Initial projects developed by staff for junior students (years 7 – 10) included the design of a Mars Rover vehicle, investigating the scientific and societal implications of a pandemic, building a rollercoaster to specification and creating a liveable Minecraft world for a hypothetical exoplanet with extreme weather conditions. Linking the projects to real-world situations and potential future scenarios was a driving concern for teachers.

> I've got the Year 9 PBL, which has a science and maths focus, and we have called it Space X. Space X is the company that Elon Musk runs, and there's been so much talk about the idea of colonising Mars, and so we thought, 'Well, we need vehicles to use on Mars now.' So our students have been designing their own vehicle to use on Mars that promotes safety. So throughout the whole process they have had to research Mars, they have had to choose their own area on Mars. So we actually get Google Maps on the satellite view and they choose a spot on the surface, and then they have to design a vehicle that can navigate that terrain and then perform whatever its purpose is. And then that idea we take to Tinkercad so that they can 3D-design it and then 3D-print it as well. So that gives them the opportunity to really learn in-depth about the technology behind vehicles, but also understand common societal needs. They're starting to realise that there are reasons why we have things like seatbelts and sensors on cars. (Brad, Teacher)

Novel unit design, however, is only one part of an effective STEM PBL classroom. Teachers noted that STEM PBL required a break with traditional classroom practices and a shift towards student ownership of learning. Both teachers and students had at times struggled with this change to routine school practices.

> I think that's also a thing on our part as teachers is sitting there in PBL and it's like, some of the kids might not be as engaged as others or as driven to do what it is they are doing. But you have actually got to let them fail. Not stand over them, 'Have you done this, have you done this, have you done this?' They've got to take ownership of what they are doing, but it's also us standing back and going, 'You figure that out.' That's hard. (Julie, Teacher)

> The Year 10s are a big struggle. And I think I've used the term 'institutionalised' before. I think they have been told to sit in a row and told what to say for so long that they do not know how to think anymore. (Tim, Teacher)

Teachers also cited students' fear of failure as a stumbling block to successful engagement in the more open-ended forms of inquiry characteristic of STEM PBL.

> A lot of our students I think have had times in their past where they have failed and that has resulted in a negative outcome, whether it be that their teacher or their parents might have been disappointed, or they are just disappointed in themselves, or they do not believe that they can do it. But what we do I feel is different, because we see that there was a failure and we are like, 'Okay, so this didn't work, what can we do differently?' And there's that opportunity there. It's like, 'Oh, you mean a failure's not the end? We can redo this?' (Brad, Teacher)

Opening up a space for students to fail and try again, and supporting students to develop resilience, was seen to be a particularly important element of STEM PBL classroom management.

> One of the teachers was saying that they'll give the kids a problem and they'll give it a go for a little bit—this is with Rube Goldberg machines in Grade 8 at the moment, in science. 'No, it doesn't work, miss, we can't make it work', and they just literally chucked their tools down. She was like, 'Well, hang on, no, you have a go; that way didn't work, what other ways can you try?' 'No, it doesn't work'. So the resilience—and I think STEM lends itself to this with inquiry-based stuff—getting these kids to persist at something until they find a solution, because there is one. (Angela, Science HoD)

The persistence to sustain an intellectual inquiry until a feasible solution is reached was also considered important to developing students' ability to engage in higher-order thinking. However, finding the right level of cognitive difficulty for tasks while taking into consideration students' diverse needs and abilities was an area of apparent tension.

> That's been a real push for us this term, as I start to do a bit more work around that critical thinking area, is making sure that we are challenging the students to think, and they cannot think if the level of content is too hard for them to access. So it's bringing that level of content down and then we can increase the level of thinking, and then we can slowly build up from there. (Steve, IT HoD)

Providing the individual and group coaching required to support students to engage with extended inquiry projects was also seen as challenging in the school's large classrooms—at times exceeding 50 students. Teachers noted that smaller classrooms would potentially facilitate higher levels of student engagement:

> I'm hoping for a smaller class. I'm hoping for all STEM classes to be smaller, even if we have more classes in total. I think 20, 22, is a good number to work with. Yeah, smaller numbers to really build that engagement or build that focus. (Tim, Teacher)

Theme 3: Multi-Dimensional Assessment

According to Marshall (2009), assessment in STEM should be 'generative, understanding, performance-based, and multidimensional' (p. 54). Assessment is intended to allow students to demonstrate proficiency through often novel forms of evidence such as research projects, prototype and product designs, multimedia presentations, exhibitions and expert panel presentations (Marshall, 2009). In the context of PBL, Larmer et al. (2015) similarly emphasise the importance of giving students the opportunity to create a public product to be shared with an audience beyond the classroom. This was seen to encourage students to perceive their work as worthwhile and of value not only to themselves, but to others in the school and wider community (Larmer et al., 2015).

Conceptualising appropriate assessment aligned with the goals of the STEM PBL programme at Wattle State High School was considered a work in progress that required teachers to devise new ways of defining and measuring success.

> At the moment, because it's brand new, we have assessed more on 21st century skills, as being the main driving tool; so how are students working, what are their levels of problem solving, what are their levels of collaboration, all of those sorts of things. (Steve, IT HoD)
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> So things like communication, teamwork—there's self-reflection in the assessment task, there's a lot of different areas. Also elements from curriculum as in their analysis of data, inquiry skills, because the program still needs to link to our curriculum subjects. But it's very different to, say, a normal science task sheet. (Amy, Teacher)

While Wattle State High School teachers embraced the challenge of incorporating holistic assessment of twenty-first century skills within student learning progressions, they recognised that more work was needed to ensure the STEM PBL programme could be comprehensively mapped to curricular standards.

> So it's very much now, 'Okay, let's look back at the units we've done, what part of the curriculum fits into that?' Or, 'Do we need to make minor tweaks to the way we assess it?' So maybe not the unit of work, but just what is being assessed; does there need to be an extra question in there that means that we can hit that criteria? (Steve, IT HoD)
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> So that's something we are really trying to work on for next year with the Year 8 roll-out—changing all our criteria sheets to map those four or five—depending if you want to STEM or STEAM it—areas of a grading matrix. At the moment, we are hitting a lot of technology side of the Australian curriculum, which is really

> good, but, because it is STEM, it's an integrated subject. We're trying to get a little bit of everything, or at least that's the goal. (Tim, Teacher)

A related challenge for teachers involved fostering students' ability to demonstrate deep learning and content mastery through performance-based assessment tasks. As compared with written reports or exam-type assessments typical to secondary classrooms, culminating tasks within STEM PBL require a complex amalgamation of research, data analysis, representation and communication skills that need to be developed in tandem with learning-appropriate content.

> When students did their class presentations, they clearly went to the internet and found the first fancy-sounding thing they could, and then they did not even understand what it was they were reading. So, we have worked a lot on, 'Right, how do you communicate this as you? What shows that you understand?' Because if you cannot explain it to us then we do not think you understand it. And once you are able to explain to other people, that's the first step towards being able to show your understanding. Once you can explain it to everyone, that's the mastery of the information right there. (Brad, Teacher)

Inviting experts into the classroom to provide formative feedback midway through the STEM PBL programme was noted as highly beneficial in supporting students to improve the depth and complexity of their assessment products.

> In the middle of the PBL we have just had our experts come in and do a gallery walk and talk to all the kids to provide feedback on what they have done in the last eight weeks. And some of them had to start again. They're like 'It's all wrong.' And I'm like, 'Is it all wrong?' And then you'd have the conversation and they are like, 'Oh no, it's not all—we just haven't done this part.' And they have taken on the feedback and kept going instead of just going, 'I'm done.' They've taken it all on board and actually gone, 'Okay, let's fix this.' (Julie, Teacher)

A significant positive outcome of the programme's performative assessment tasks was the creation of an avenue for richer engagement with parents and community members around student learning in STEM.

> Some of their exhibition nights and things have been outstanding, really good. The pandemic one last term, it was brilliant. It was a community event in the end, with the number of parents and the students' younger siblings that would come along. It was brilliant. And it was great to see—because the parents actually get to see what they do in the classroom—as opposed to, 'Here's your grade on your assessment task.' It's like, 'Well I can't give you my assessment task because it's a diorama, it's a video, I've made a backpack over here, a survival kit.' (Steve, IT HoD)

Discussion

Internationally, equity of access to STEM education is the focus of extensive policy and public attention. Articulating a vision for STEM education in low-SES schools requires a deep understanding of what works, along with recognition of potential tensions. While there is widespread awareness of challenges specific to low-SES schools that impact all areas of learning—such as limited physical and human resources—there is less data demonstrating the ability of low-SES schools to innovate pedagogically to work around immutable constraints and deliver quality STEM programmes. The data presented in this paper demonstrates that delivering STEM through a PBL approach encourages teachers and students to reframe possibilities within a secondary setting. Extended classroom observation and interviews with teaching staff have illuminated three defining characteristics of a successful STEM PBL model in a school experiencing disadvantage—Building the Culture, Promoting Active Learning and Multi-Dimensional Assessment.

Building the Culture is understood to be an integral precursor to successful STEM PBL (Larmer et al., 2015). Overall, key elements of Wattle State High School's culture were seen to have laid the groundwork for a flourishing integrated STEM PBL programme. A school ethos focused on creating pathways and possibilities for diverse students provided a supportive foundation for conceptualising how STEM might best meet the needs of the student cohort. Support from school leadership to innovate encouraged teaching staff to be creative in designing STEM curriculum. Allowing teachers to self-select into the STEM PBL teaching space ensured passionate teachers were charged with launching the programme and sustaining it in its first year. Self-selection also helped mitigate the challenge of teachers working 'out-of-field' in STEM, a relatively common occurrence in low-SES schools (Weldon, 2016). Sufficient time for teachers to plan and work collaboratively was reportedly essential to embedding radically new ways of teaching. Teachers were aware, however, that further work was needed to determine the best ways of sustaining collaborative practice among teaching staff across disciplines and year levels. As noted by Gardner and Tillotson (2019), 'There is limited understanding of how pedagogical innovations are internally developed and maintained by teachers' (p. 1285); attention to collaborative structures that support STEM innovation warrants further investigation.

Promoting Active Learning is instrumental to most integrated STEM approaches and has been shown to improve student learning outcomes (Barron & Darling-Hammond, 2008). At Wattle State High School, finding ways to engage reluctant learners motivated teachers to experiment and refine their pedagogy. STEM PBL projects designed by teaching staff were highly experiential in nature and were deliberately linked to real-world situations and future scenarios in the hope that students would find these projects both relevant and engaging. While students did appear to find the selected STEM PBL topics interesting and engaging, navigating a fully realised version of active learning in the classroom appeared at times to be a struggle for both teachers and students. Shifting ownership of learning from teaching staff to students was another area of apparent tension. With students accustomed to playing a relatively passive role in the classroom, teachers felt unsure of when to assist students and when to step back. The highly diverse nature of the classrooms, with students operating across a wide range of academic ability levels, also created uncertainty in terms of how much scaffolding should be provided to individual students, and whether too much teacher intervention would negate the positive effects of PBL, particularly in relation to student resilience and autonomy. Considering the intellectually challenging nature of STEM PBL and the desire of teaching staff to be fully inclusive, further investigation of academic differentiation in diverse classrooms would be of practical assistance to teachers in this space. Large class sizes at Wattle State High School were also seen as a barrier to meeting the needs of diverse students in STEM PBL, particularly in relation to spending quality time conferencing with individual students and groups. While class sizes are often fixed, the provision of additional learning support staff, teaching assistants and volunteers may help address the shortcomings of large class sizes in highly diverse schools. Overall, the issue of how to engage all students in active learning was a very significant area of tension for teaching staff and highlights the importance of providing ongoing support for teachers practicing open-ended pedagogies (English, 2017).

Multi-Dimensional Assessment was identified as a critical component of a successful STEM PBL programme. More than a means to ascribe grades, assessment allowed students to develop by representing their learning to public audiences in novel and generative ways (Marshall, 2009). For the teachers in this study, designing creative forms of assessment seemed to be an enjoyable component of planning STEM PBL units and a great deal of thought went into both the design of appropriate assessment tasks and the creation of holistic assessment rubrics incorporating twenty-first century skills alongside traditional knowledge-based and inquiry criteria. A greater emphasis on formative assessment, including mid-term input from outside experts, was seen to encourage students to develop a growth mindset and view feedback as a tool for further development. Celebration of success with parents and community members at the completion of STEM PBL projects was seen to be a positive way of bringing the community into the classroom. Perhaps a result of the relative novelty of the STEM PBL programme, teachers struggled to ensure students had the appropriate skills to convey their knowledge mastery and skill development through performance-based tasks. Students sometimes found it quite difficult to pull all the threads of their learning together within a coherent, creative public presentation. While STEM PBL research suggests that students should 'be able to present their understanding in the same way as professionals in the discipline' (Slough & Milam, 2013, p. 22), the experiences of participants in this study indicate that students may require significant support, guidance and time to meet this goal.

Conclusion

This paper provides localised insight into some of the enablers and challenges experienced by a low-SES junior secondary school implementing a quality STEM PBL programme. Aiming to enhance opportunities and pathways for students experiencing high levels of economic disadvantage, Wattle State High School faced issues common to low-SES schools, including limited time, funding and staffing resources to implement and sustain quality STEM pedagogy (Lowrie et al., 2017). Despite these barriers, the school has experienced success in this domain through a shared dedication to continuous improvement of its STEM PBL programme. While this paper provides a brief snapshot of some of the key foundations of the school's STEM PBL programme, further research is needed to determine the best means of scaffolding teachers' and students' navigation of novel and dynamic learning environments in similar educational settings.

Compliance with Ethical Standards This study was approved by the Australian Catholic University Human Research Ethics Committee (approval no. 2019-123H).

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