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Abstract: This ethnographic study reports on the findings from seven English secondary schools that participated in Project Faraday. The project was funded by the Department for Children, Schools and Families to build innovative learning environments to encourage students into upper secondary inquiry-based STEM. Despite the innovative classrooms, the schools emphasised A-Level university entrance science. Technicians prepared for specific science subjects, although teachers acknowledged the value of inquiry-based pedagogies. UK policies prioritising A-Level assessment were found to be impeding inquiry-based STEM, although wealthy schools had the resources to facilitating both A-Level science and inquiry-based STEM through clubs and co-curricular programs. Our data elicited important general design principles to inform makerspaces for inquiry-based STEM for adult learners. We concluded that initial teacher education programs should provide graduates with pedagogical experiences in makerspaces that enabled them to appraise contemporary school learning environments; and be informed about securing safe, flexible, and durable equipment for students.

Key terms: ethnography, initial teacher education, innovative learning environments, Project Faraday, STEM education

Introduction

In recent years the link between innovative learning environments (ILEs), and Science, Mathematics, Engineering and Technology (STEM) education has become an area of growing interest in initial teacher education (ITE) programs (Imms & Kvan, 2021). This has implications for students in ITE programs, and the professional development of practising teachers in how to model ILEs with novel classroom spaces and furnishings to enhance learning and is primarily based on a social constructivist theoretical framework (Byers et al., 2018; Hoff & Öberg, 2015).

This ethnographic research (Creswell, 2014) aligns with the Organisation for Economic Cooperation and Development (OECD) STEM education policy settings (2013a; 2017), and research into ILEs (Davies et al., 2013; Davies et al., 2018; Fadel, 2012; Nadelson & Seifert, 2017), supporting the notion of *holistic learning ecosystems*. These holistic learning environments have implications for contemporary ITE, and the professional development of teachers. Importantly, these STEM education and ILE policy settings are also underscored by the OECD's future skills for the 21st century agenda, often termed the 4C's — *creativity, critical thinking, communication, and collaboration* (Daly et al., 2019; OECD, 2018; Schleicher, 2012), which emphasises social constructivism (Barak, 2017; Piaget, 1985; Vygotsky, 1978).

This paper positions the aggregated data from 32 participants working in seven English secondary schools conducted in late-November 2019, associated with the UK Government's Project Faraday (PF) to promote inquiry-base STEM/Science after the age of 16 years through the inclusion of ILEs (GovEd, 2015).

Research Aim

The researchers aimed to elicit guiding principles on how participants' experiences with PF-ILEs could inform a proposed internal building upgrade to create a STEM teaching and learning 'making spaces' for ITE programs.

This study is informed by other research being conducted into holistic learning ecosystems (Association for Learning Environments (ALE), 2021; Imms & Kvan, 2021; LEaRN, 2019) and supports leading pedagogical approaches for STEM education (Australian Academy of Science, 2021; STEM Learning, 2021; Western Australian Government, 2021). The background and context for this research into the UK's PF-ILEs was reflected in the Australian Government's post-GFC spend of circa AUS $16 billion for school building upgrades (Australian National Audit Office, 2010; Harrington, 2011). This funding stimulus, saw education policy initiatives linked to enhancing STEM participation across K-12 Years consistent with global benchmarking (OECD, 2013a; 2017; 2018), and inquiry-based pedagogies (Barak, 2017; Tytler, et al., 2008).

Overview of Innovative Learning Environments

The OECD (2013a; 2017) acronym ILE conceptualises a notion of an organic holistic learning ecosystem as part of a social constructivist theory (Barak, 2017) that supports inquiry-based learning in STEM education (Fraser, et al 2021; GovEd, 2015; Imms & Kvan, 2021; LEaRN, 2019; Nadelson & Seifert, 2017; OECD, 2017). The OECD reinforced the pedagogical importance of ILEs to motivate students' interest in studying STEM subjects and creative problem-solving (i.e., 4Cs). The intent to fully include ITE programs to enhance pedagogical engagement of ILEs (Byers et al., 2018; Fisher, 2016; Granito & Santana 2016; Imms & Kvan, 2021) is still developing. More recently the concept that an ILE should also include a more holistic approach and assess the socio-emotional climate of the classroom as well is being explored (Fraser et al., 2021). Teacher professional learning surrounding ILEs competes with other educational priorities (Imms & Kvan, 2021).

Since 1921 enhanced learning has been linked to innovative classroom designs as demonstrated with the US National Council on Schoolhouse Construction (NCSC) (ALE, 2021). By 1971, Western classroom designs were shifting towards open flexible planning especially in primary/elementary contexts, and without teacher induction to support teaching in these spaces, many teachers reverted to traditional teaching in row and column organised classrooms (ALE, 2021).

The Politicisation of STEM

The political importance of STEM in K-12 education is reflected in the volume of education publications, with most originating from the Anglosphere: the USA; Australia; Canada; Taiwan, and UK (Brown, 2012; Li et al., 2019; Li et al., 2020). The STEM acronym was used in 2001 by Judith Ramaley — then the Assistant Director for Education and Human Resources at the US National Science Foundation (Koonce et al., 2011; Hallinen, 2015; Lyons, 2020; Mohr-Schroeder et al. 2015). The acronym entered Congressional records (House Science and Math (STEM) Education Caucus, 108th Congress) in 2004 (Lyons 2020).

STEM has also evolved into an equity label linked to the underrepresentation of women and minorities in STEM careers (Cardador et al., 2020; Koch et al., 2014; Sax & Newhouse, 2019). Advocates claimed STEM careers provided higher salaries (Magarian & Seering, 2021), consequently politicians became sensitive to constituents' perceptions of STEM inclusivity, fostering educational policies based on short-term electoral needs (Bell, 2015; Koch et al., 2014). Subsequently, many Western governments like Australia and the UK became politically reactive when secondary education was perceived as not attracting enough students to meet industry expectations (GovEd, 2015; Johnson et al., 2020; Office of Chief Scientist, 2020; STEM Learning, 2021).

The challenge for ILEs that support age-appropriate STEM pedagogy (Australian Academy of Science, 2021; STEM Learning, 2021); however, is confounded as it occupies a polymorphous format. STEM teaching and learning approaches currently span multiple formats from discipline-centred STEM subjects, which emphasise the role of age-appropriate pedagogical content knowledge (PCK) (Shulman, 1986; 1987) in a discrete discipline to interdisciplinary teaching approaches (Mildenhall & Cowie, 2021). Integrated STEM education approaches often assume problem-based or inquiry-based learning (Australian Academy of Science, 2021; Barak, 2017; Government of Western Australia, 2021; STEM Learning, 2021; Tytler et al., 2008).

Project Faraday

> *The UK's Project Faraday was named after the British scientist Michael Faraday (1791-1867) for his contribution to electromagnetism and the invention of the electric motor* (Cantor, 1991).

The UK Blair Government developed an ILE policy — the *Ten-Year Science and Innovation Framework* 2004–2014, to review the *Building Schools for the Future* by employing best practice creative designs for school laboratories to integrate the latest research to promote inquiry-based learning (GovEd, 2015). By December 2006, the Government initiated a project for secondary school STEM/Science education engagement for the Department for Children, Schools and Families, now the Department for Education (Department for Children, 2008), directly aimed at motivating students to study science after the age of 16 years. The project engaged a consortium of architects/designers, with secondary schools across the UK invited to apply for £1 million to build STEM ILEs (GovEd, 2015). Project Faraday concluded in December 2007 and Government Education stated :

Support, through excellent and appropriate facilities … to improve attainment levels in *science and encourage more young people to take science at higher levels*. Fully reflect the requirements of the new science curriculum. Explore the ways in which the whole school building and its grounds, not just the laboratories themselves, *can enable and enhance innovative and interactive methods of teaching science* [emphasis added]. Develop design ideas that can act as 'exemplars' for science provision, to inspire and inform all future building projects (GovEd, 2015, para. 9-10).

The PF project was disrupted by the Global Financial Crisis (GFC) — 2007-2008, and in 2010, the Cameron Government was elected with a mandate to tighten the fiscal settings, and to provide educational continuity with previous administration's initiatives. Some PF schools finished their build in 2009, whilst for other schools, financial accountability became a priority (Beauvallet, 2014; Bell, 2015; Coughlan, 2015; Granoulhac, 2018).

Today, many English schools still identify with PF-ILEs and ALE (2021), showcasing STEM/Science classrooms and relationships with the National STEM Learning Centre (NSLC) at the University of York. The NSLC offers a range of pedagogical support for teachers through its global networks, and significant industry partnerships including BAE Systems; GSK Enthuse; Rolls-Royce; Vetex; BP; Lloyd's Register foundation; UK Space Agency, and the European Space Agency (BAE System, 2021; STEM Learning, 2021).

Inquiry-based STEM Pedagogy

The concept of inquiry-based approaches for STEM education is underpinned by established pedagogical content knowledge (PCK) readiness to apply multiple skills and understandings from several STEM disciplines (Tytler, et al., 2008). This approach also supports critical thinking that is essential in developing solutions to problem-based projects such as robotics and engineering (Nadelson & Seifert 2017). Research currently identifies five integrated STEM teaching and learning models: integration of STEM content; problem-centred learning; inquiry-based learning; design-based learning; and cooperative learning in small groups with a teacher facilitator (Thibaut et al., 2018). Despite interdisciplinary claims (Mildenhall & Cowie, 2021), STEM is often enacted as the historical reproduction of secondary school curricula, and just a neologism for science education (Carter, 2017). This narrow remit is often criticised for being linked to neoliberal political agendas for short-term policy adjustments for capital production (Granoulhac, 2018). Researchers' claim the constant redirecting of the educational agenda disrupts previous reforms (Bell, 2015; Gurd, 2013; Lingard et al., 2016). This narrative is often in tension with the broader notion of holistic learning ecosystems as reflected in OECD's future skills of the 21st century 4Cs (Barak, 2017; Daly et al., 2019; OECD, 2018; Schleicher, 2012; STEM Learning, 2021) and ILEs which supports this holism. Policy shifts, disrupt the development of age-appropriate pedagogical content knowledge (Shulman, 1986; 1987), and *Technological Pedagogical and Content Knowledge* (TPACK) (Barak, 2017; Mishra & Koehler, 2006). This adds to the disruption of the long-term development of holistic learning ecosystems, which requires teacher professional learning commencing from ITE programs (Barratt et al., 2013; Imms & Kvan, 2021).

Factors Disrupting Innovation

Unlike-primary/elementary schools where innovative STEM activities using inquiry-based learning approaches are more easily facilitated (Australian Academy of Science, 2021; STEM Learning, 2021; Tytler et al., 2008), secondary schools focus on specific subject disciplines, and as such need to accommodate explicit timetables, specialist staff, and required examinations in upper years that can impede pedagogical innovation (Bell, 2015; Lingard et al., 2016). Government directives regarding science in the curriculum has also been shown to inhibit pedagogical innovation, especially in periods of economic downturns

(Granoulhac, 2018). Given the largest expenditure in education and specifically schools are salaries, ongoing teacher professional learning is often perceived as optional (Chu et al., 2017).

Political leaders support STEM education at a rhetorical level, but often fail to appreciate the diverse factors influencing the pedagogical learning ecologies, as the rhetoric often shifts to back-to-basics education policies which can impede interdisciplinary approaches to STEM (Bell, 2015; Nadelson & Siefert, 2017). The former permanent secretary at the UK's Department for Education claimed there should be no more major changes to the curriculum, qualifications, or structural changes without an independent body to protect long-term education reforms which are evidence-based and secure from party politics (Bell, 2015).

The Impact of Global Assessment

Prior to Ramaley's STEM movement, the OECD in 1997, established the Programme for International Student Assessment (PISA) to review science, mathematics and reading performance of 15-year-old students (OECD, 2018; Robertson, 2021; Savaget & Acero, 2017). PISA also supported the International Association for the Evaluation of Educational Achievement (i.e., known as IEA), facilitates Trends in International Mathematics and Science Study (TIMSS) (Mullis et al. 2016). Importantly, PISA and TIMSS influence global political perceptions and investments in STEM education, teacher education, and the perception of the political value of STEM disciplines (Eras, 2016; Robertson, 2021; Zhao, 2020).

University ITE programs are impacted by international perceptions of economic and employment enhancement (Lingard et al., 2016). The OECD's policies impact approximately 37 nations where PISA benchmarking influences STEM/Science education (OECD, 2018). Australia and the UK, secondary schools frequently market their educational standing on a narrow band of high achieving senior secondary students entering university using competitive examination results. In Australia, the Australian Tertiary Admissions Rank (ATAR) has increased public accountability pressure in schools for outcomes (Australian Curriculum, Assessment and Reporting Authority, 2014; Lamb et al., 2015; 2016; Lingard et al., 2016). In England and Wales, Advanced Levels (A-Levels) which were established in 1951, initiated upper secondary examinations for students to encourage a range of academic subjects that aligned to the course selection criteria of prestigious universities (UK Parliament, 2003). In the past decade both the UK and Australian Governments have elevated an upper school focus and assessment of STEM subjects for university entrance to support national economic outcomes (Western Australian Government, 2021), and these influence the design of ITE programs.

Teaching upper secondary STEM from a disciplinary perspective can create a tension with other key policies that aim to foster holistic interdisciplinary STEM inquiry-based learning that link creativity, critical thinking, communication, and collaboration, and support careers of the future (Bell, 2015; Fadel, 2012; Dimick, 2008). Bell — the former head of the UK's Office for standards in Education (Ofsted) claims that holistic learning associated with creativity and curiosity found in aesthetic inquiry is essential to a successful STEM/Science education (2015).

Competing OECD Policies

In many respects, the OECD can be seen to be fostering two narratives: one supporting holism through the 4Cs (Barak, 2017; OECD, 2013b; Davies et al., 2018) which are key to collaborative inquiry-based STEM education embracing authentic problem-solving (Akerson et al., 2018; Means et al., 2017; Parker et al., 2016; Shulman, 1986); and the other which focuses on accountability through summative discipline-centred assessment (Alexander & Potter, 2005; Lingard et al., 2016).

One of the obstacles to inquiry-based STEM PCK (STEM Learning, 2021), is the public emphasis placed on success in upper secondary STEM such as science and evidenced through examination results, where politicians and parents consider subject performance used for university entrance as a key indicator of quality, and *raison d'être* for economic productivity (Granoulhac, 2018). This contrasts with research claiming secondary school students prefer inquiry-based learning STEM experiences such as robotic-programming using a social constructivist mode (Barak, 2017; Chu et al., 2017; Sokolowski, 2018; Tytler et al., 2008). The issue for secondary schools, teachers, parents, and students is a form of cognitive dissonance (Vaidis & Bran, 2019) where educational policy shifts create perceptions of policy inconsistency (Bell, 2015), where creative problem solving in upper secondary years, often marginalised by the emphasis to pass examinations to enter universities, disrupts holistic learning approaches in schools.

Research Methodology

Following ethics approval, seven English PF-ILEs schools were randomly identified through online profiling then contacted, and principals were provided with consent forms.

The research questions focussed on open ended qualitative responses (Creswell, 2014) that enabled participants to detail:

- STEM/Science teachers' perceptions of the impact of PF-ILEs.
- Science technician's perceptions of PF-ILEs.
- Students' perceptions of PF-ILEs (i.e., in some schools).
- Perceptions on how the PF-ILEs were integrated into existing school buildings and grounds.
- Perceptions on how PF-ILEs enabled upper secondary inquiry-based STEM/Science learning.

Several measures were employed to ensure anonymity of the responses from the schools which included:

- Open focus groups for questioning participants.
- The participants being determined by the principal, or a senior associate.
- Multiple conversations occurring with the researchers.
- No school or participant would be identified by name or any identifying descriptors.

Self-selecting schools included middle to upper socio-economic catchment which were easily identifiable online, and as such:

- Confidential building costs were not disclosed.
- Digital images which could identify a school, were only used for reflective purposes.
- Aggregated data were employed to protect a school's identity.

Conceptual Framework

This research follows a purposed ethnographic interpretivist framework, and consistent with social constructivist theory (Barak, 2017; Piaget, 1985; Vygotsky, 1978). The epistemological assumptions of our research support a socially constructed reality (Creswell, 2014; Crotty, 2020; Husserl, 1965; Qin, 2013).

The purpose of an ethnography is to provide insights into the culture-at-work within the seven Project Faraday schools. The ethnographic approach focusses the researchers' interactions with the participants for interpretation within a bounded system (Creswell, 2014; Crotty, 2020) because of the PF-ILEs.

The data were elicited initially through an informal *focus group* approach (Creswell, 2014; Creswell & Poth, 2018), informed by semi-structured questions to engage participants' views of -PF-ILEs. The interactions were informal with open-ended questions to engage the participants. Any interrogative tone to secure a mutual sense of reflexivity was avoided (Creswell & Poth, 2018).

The participants shared perceptions of the use of PF-ILEs; STEM education and pedagogies; teaching experiences, and STEM partnerships. Perceptions of strengths and weakness covering the PF-ILEs were encouraged. The culture-sharing (Creswell & Poth, 2018) covering collective and/or the distinctive aspects of the PF-ILEs. Only aggregated data were used in the interpretation within the limits and ethical protocols of the purposed case studies engaged (Yin, 2014).

The research methodology included purposed interactions (Creswell, 2014; Yin, 2014), including participants that had been part of the initial planning phase of PF. Science technicians were included to provide practical perceptions of the physical and material classroom preparation and class scheduling (Qin, 2013).

Digital photography and videos were used to record furnishings, and PF-ILE class designs. All the related images remained part of the diary records for reflections adding to the data and the analysis of information not initially recalled by-researchers during focus group discussions (Denzin & Lincoln, 2005).

Reflective notes were made after each half-day visitation and the themes that emerged from the diary notes provided rich qualitative data and summary statements (Qin, 2013). Image reflections triggered more discussion and triangulation between the researchers. The digital images allowed for detailed examination of PF-ILEs, and shared STEM experiences (Denzin & Lincoln, 2005).

Triangulation of reflections, data, and images between the case studies enhanced the validation of the data collected (Denzin & Lincoln, 2005). The literature reviews informed the data collected and the interpretation of digital images (Phillippi & Lauderdale, 2018) were presented as a narrative after coding was completed (Denzin & Lincoln, 2005; Eisenhardt, 1989). The summary of the field notes confirmed researcher consensus (Creswell & Poth, 2018).

Analysis of Findings

The following is a re-storying of participants' perceptions using thematic vignettes.

Building Challenges

The following findings were sourced from experienced senior science teachers and some principals who were at the schools during the commencement of PF. Participants who came to the PF-school after 2009 did not have any direct experience with the build process. One participant reported: *"The whole Faraday thing was complex … especially trying to get enough funding to realise the preferred design".* Another participant claimed: "*… a million pounds [circa US$ 1.5 million, 2021] does not secure a great deal of building renovations"*. Another explained: *"Our senior science teacher helped designed our new classrooms".*

The data reported several factors impacting the cost of PF-ILEs. A participant recalled: *"The planning process was quite difficult … local planning authority bylaws and the heritage compliance was always a headache … delays and workplace safety problems".* Another participant disclosed: "*Our multi-story construction just swallowed up money … our old school was full of unseen problems".* The data reinforced that senior science colleagues were engaged in the design and management of the building process and highlighted the navigation of local English council planning bylaws resulted in different starting and completion times across the case studies. One participant said: *"A great deal of time was required to interpret building regulations, and this often resulted in … modifications of the original design … cost over-runs".*

Compliance to English heritage conservation requirements in older schools was an issue. A participant stated: *"We kept on digging into layers of hidden English history … old plumbing"*. The data reported excessive costs, linked to heritage compliance, limited the architectural interpretations. One teacher said: *"Our new build ended up as a new meeting room … an improved science laboratory … some extra storage space … staircases are expensive!".* Installing new plumbing and integrating new electrical services were reported as being very expensive and labour intensive. Heritage issues made it difficult for both architects and schools to estimate costs. Cost over-runs required some schools to seek additional funds. As one teacher explained: "*We opted for more economical furnishings … it was difficult at times".* Some schools were required to make compromise to finish the ILEs. Specific costs were not disclosed; however, it could be reasonably assumed replacing services in heritage schools had an impact on design and scope of original works. One participant exclaimed: *"What an experience! Demolition and material management … always safety issues around student movement … trying to live with the noise … the chipping and drilling … the removal of dusty masonry whilst classes continued*".

The data suggested the quality of the build was influenced by the location of the school. Building on semi-rural land that was not heritage listed, had an advantage over those with a heritage listing.

Design Features

The data recorded a range of architectural solutions to enhance the STEM/Science culture-at-work, which is consistent with findings of other researchers (Barratt et al., 2013; Fisher 2005; Fisher, 2016; Fraser et al., 2020; Imms & Kvan, 2021). Four key design themes emerged from the PF-ILEs: *inclusion of students with diverse learning needs; environment controls and outside access; re-purposing materials in ILEs; and British nationalism and STEM.*

As one teacher explained: *"The [Faraday] spaces are architecturally distinctive … they allow students to breakaway … but sometimes kids need to study in private … the withdrawal spaces are used a lot"*. Spaces in the more comprehensive PF-ILES included curved and/or non-parallel walls. These spaces included soft furnishings that were durable.

Although most PF-ILEs were architecturally pleasing, there were issues with these spaces. As one teacher reported: *"In our open planned science room often both visual and noise issues which affects both students and other teachers … like people walking and talking when using open thoroughfares … this is a major distraction"*. One student explained: *"I do not like loud group work I really want my own space where I can concentrate".* A teacher stated: *"Really, planning needs to include a range of special learning styles … I have students who a prefer independent learning over group work".* Another student stated: *"I get stressed with too much with noise … I need my space … I want to focus on my project work without all the distractions of other kids talking over each other".* The data suggested the ecology of learning requires more than just aesthetically pleasing spaces. One teacher claimed: *"What really frustrates me is trying to control lighting, air-conditioning, and heating associated with seasonal variation … excess external lighting [sun] or a lack of environmental controls restricted the types of science learning experiences you want to plan … it become too hard".* As one technician explained: *"The technical interface with climate control … well it needs to be durable and not subject to expensive repairs and downtime … all this just kills any creative science activities … it becomes an effort for the teacher … and then the kids play up — so why bother …".*

Many PF-ILEs provided generous visual access to external areas such as vegetable gardens, chicken yards and natural settings. Other environmental innovations included: an open-air orrery for planetary movement; spaces for exhibiting student artworks, and an indoor garden that included a space for student presentations consistent with ILE research (Barratt et al., 2013; Imms & Kvan, 2021). In late-November in England, the ability to undertake an outdoor class would be highly problematic. A teacher stated: *"The weather does limit the time spent on outside activities … it is very unpredictable".* More suitable temperatures which typically coincide with summer holidays. Most of the science instruction is classroom-based given that the weather in England is problematic. Overall, the visual transitions from learning spaces to the external environment were available to school communities, the positive aesthetics were considered a marketing advantage for prospective students and parents.

Sustainability was evident during PF-ILEs visits, for example, repurposed materials were included in some architectural designs. One of the teachers explained how: *"Our design team included an emphasis on sustainability through the inclusion of industrial and repurposed heritage materials … great to see happening in our new learning spaces … the design reinforces a strong value statement for our school".* Several case studies provided both aesthetic and sustainability in the build. The data suggested that some wealthier schools had exceeded the available Faraday funding and had accessed other funds. Overall, the PF-ILEs interpretations created a perception of a positive school environment well beyond the box-like 20th century secondary school designs found in post-war school of the 1950s.

During the site visits it was common to see quality exhibitions that emphasised science as a human endeavour. Exhibition spaces provided STEM concepts and themes, including, microscopic images of insects, plants, fungi, viruses, and micro circuits. Other exhibitions had images of historical connections to major British accomplishments from the Industrial Revolution through to the 21st century including engineering, chemistry, biology, astronomy, medicine, and aerospace. At the time of the visit to schools the Brexit debate was at a high point; however, British nationalism and excellence in STEM was a major political priority. For example, "Make Britain Great Again" was a popular slogan associated with the STEM learning areas visited, reinforcing the UK's central role from the Age of Enlightenment emphasising Isaac Newton, and the scientists and engineers from the Industrial Revolution, including Michael Faraday, James Watt, Frank Whittle, and others (Giffard, 2016; Guicciardini, 2018; Hudson, 2009; Miller, 2015).

Most participants held positive perceptions towards PF-ILEs. Data collected suggested that all seven participating schools were proud of their buildings and artefacts.

The Impact of the Global Financial Crisis

Participants, who were teaching both before and after the completion of the PF-ILEs, post-2009, remembered a very positive lift in the school's culture-at-work consistent with the findings of Barratt et al., (2013). One participant said: *"We were very proud of our Faraday classrooms … the only negative sentiments that I recall happened around the time of the global financial drama … money became tight … it was a shock … lots of things changed … also some good people moved on".*

The data collected in this study demonstrated a distinction between the length of experience of teacher' involvement with the PF-ILEs and disposition. Several experienced participants recalled the PF-ILEs being used to advance STEM/Science engagement. A teacher recalled: *"In the early years we were really motived by the new spaces and played around with some ideas … I think all our classes were excited by the novelty of it all … but it was short lived".* Recently appointed teachers did not share the desire to explore progressive pedagogies. Feedback provided reported the need for teachers to follow the specific science syllabus for chemistry, physics, and biology. The same teachers had an appreciation of inquiry-based science pedagogy but were very focussed on planning for a discipline-centred science. Some participants claimed that the GFC had shifted their school's interpretation of the PF-ILEs. As one teacher explained: "*The GFC really hit our school … our administration decided to introduce traditional space allocations to save money … yes without any real consultation regarding our Faraday classrooms … we just had to cater for more students".*

Several conversations with participants suggested that financial sustainability was a priority following during the post-GFC years. It was apparent that some school bursars were dismissive of progressive pedagogy. A participant confirmed: "*The increase in student numbers … helped pay for school costs, we saw a greater number of students sharing the new spaces [PF-ILEs] … really it was the bursars that judged what was non-essential [i.e., savings over pedagogy]".* However, participants in schools that were well resourced did not recall such measures.

Several participants claimed that after 2010, the UK Government's educational policies reinforced the need for metrics to support and provide a summative assessment (Beauvallet, 2014), which had an impact on narrowing pedagogical practices. Several participants spoke of the anxiety of the government directives. One participant claimed: *" It is normal for our school to experience regulatory checks by [education] inspectors".* An experienced teacher explained: *"I think that all this compliance creates stress … it prevents our staff from taking creative risks … not much time to work together you know … just focus on getting the classes covered … time is an issue … best to keep your job".* One participant stated*: "Our new colleagues are very conscious of staying employed to be honest … I guess secure work is a priority … yes when compared to moving outside the curriculum [science classes]".*

Several participants suggested there was a relationship between A-Level results as a marketing tool to attract higher enrolments. A teacher claimed: "*In our school good final examinations results attracts new parents and students … success is all about getting into a top university …. This generates new fees from parents".* The researchers concluded that university entrance requirements had created a more traditionally focussed approach to STEM. Furthermore, reallocating PF-ILE's spaces upon traditional classroom calculations would has the potential to impede both collaborative inquiry problem-solving and collegial engagement. The data suggested competition between English schools to market the success of A-Level students is evidence to highlight entrance into prestigious UK universities (Beauvallet; 2014; Bell, 2015).

Finally, the data reported the emphasis on university entrance was impacting the type of pedagogy experienced by some younger students. Some senior participants suggested that the university entrance marketing approach adopted by their schools had created a pedagogical push down effect. A teacher claimed: "*A-Level science is influencing the way lower secondary science is being taught …* it is *driving it towards discipline-centred science [explicit learning]".* Another participant said: *"… some local primary schools were moving towards a more explicit teaching of STEM … this is so upper primary teachers can prepare their students for secondary school science".*

Technicians' Perceptions

Four themes emerged from our discussions with technicians: *safety and time management; flexible spaces; durable equipment; and securing flexible digital technology*.

As one technician explained: *"Safety is heavily regulated … especially the storage of chemicals".* Another reinforced: *"Access to service hubs in the classroom is essential … water, gas, fume cupboards and IT [internet services]"*. Time management was instrumental in the co-locating of preparation facilities along with the teaching spaces. Some co-location did allow for some opportunistic teaching moments for inquiry-based learning; however, as one participant claimed: *"It is the tight school timetable that directs what happens … also we work with specialist science teachers … they have responsibilities … the curriculum … it is about efficiency".* Another technician said: *"Basically, is it operational restraints that limit inquiry-based STEM in our school ... we have to operate in a sustainability way … it would be stressful to prepare for open ended science in several classes … not enough technical support really … I would not cope".*

Flexibility was central to the pragmatic design of PF-ILEs with services hubs which is consistent with recent research (Imms & Kvan, 2021). A technician explained: *"Science plumbing … water gas has to be fixed but strong lab benches that are moveable help teachers create flexibility in the teaching spaces … this can support different group projects … making and building … but you need to switch things back for the next class, without hurting your back".* Some teachers were exploring group work with more kinaesthetic activities supportive of inquiry STEM pedagogies. The data collected from participants reinforced the value of the technician as part of the essential cooperative laboratory support, facilitating the notion of a holistic learning ecosystem. One technician declared: "*Hands on inquiry-based science requires a great deal of extra technical coordination and time to set up and pack up".* Each technician detailed similar expectations regarding the use of space regardless of whether it was in the PF-ILEs or a more traditional classroom. The researchers concluded that learning environments required extra technical support to support innovative pedagogy.

Durable equipment was a major requirement with a technician saying: "*When it comes down to it all … schools want durability and value for money … our equipment needs to last … if it does work properly or is breaks all the time then what's the point".* Another technician reinforced: "*All furnishings need to be 'kid-proof … robust, easily cleaned, mobile, and easily secured for safety compliance reasons … also some big projects [inquiry STEM] requires students to access tools, glues … importantly this needs to be managed safely, and the teachers need to be in control … the school has other specialist workshops [design and technology classrooms] where heavier engineering tools are kept ... saws, welding and specialist teachers … we only cover the science".*

Digital technology was considered a normal expectation. Besides the storage of chemicals, security for quality displays were important for both preparation and scientific communications. One technician emphasised: *"All these kits … robotic equipment … engineering kits, laptops, tablets, are very expensive, and we are accountable for repairs, safety and security … this all takes time".* Digital equipment and smart screens were often situated at the front of the classroom reinforcing teacher-centred instruction. A technician claimed that: *"This digital technology needs to be available in all science learning spaces when required … the old fixed-screens do not provide enough flexibility for teachers".* Increased flexibility was a common theme with technicians reporting: *"We have to pay lots for tech upgrades … the old tech is so expensive to fix … centralised projectors … single 'smart TVs etc".* As one technician claimed*: "New tablets and laptops offered the best flexibility for science learning … but secure storage is also part of my role"*. Overall, storage facilities were over stocked with equipment, and every storage space was utilised. Most technicians despite providing constructive criticism perceived the PF-ILEs as a distinctive school asset.

Pedagogical Insights

Two pedagogical approaches were observed: a dominant approach explicitly focussed on discipline-centred science for A-Level achievement, and the other approach was a niche approach accommodating integrated/interdisciplinary STEM learning built around informal student-teacher interests inclusive of engineering and digital technology applications. Data obtained through observations suggested that several STEM teachers were demonstrating the development of an holistic learning ecosystem. Importantly, it was the wealthier schools that supported lower secondary years engagement in three learning contexts.

Four pedagogical insights were observed: teacher awareness of current pedagogy (PCK); inquiry-based problem solving, discipline-centred upper secondary science, and the role of digital technology.

Trends in STEM-PCK

Firstly, most of the participants were well-informed regarding international trends in STEM education. One participant said: *"We work with a variety of STEM networks … we get a great of global recognition online … the kids and parents love it … we have connections with York's STEM Learning Centre".* A social constructivist pedagogy including the 4Cs (Barak, 2017) was observed or inferred to be happening especially in some lower secondary club contexts; however, the data suggested limited opportunities in upper A-Level secondary science contexts. One of the upper secondary science teachers said: *"We often get our students working in groups from time to time when needed*". This was interpreted as limited collaborative engagement, and that participants' initial teacher education had provided a broad appreciation with inquiry-based learning consistent with the Australian experience (Australian Academy of Science, 2021; Tytler, 2008) and global exemplars found in the UK (STEM Learning, 2021).

Inquiry-Based Pedagogy, Constraints, and Successes

Participants were openly supportive of inquiry-based learning and its links to authentic problem-based STEM and appropriate PCK (Shulman, 1986); however, one participant explained that: *"Our tight science curriculum often limits the opportunities to integrate the inquiry group work … it is very difficult for upper secondary science classes … there is a fair amount of pressure from inspectors … preparing the older students for assessment [A-Levels]."* It was concluded that there was a great deal of external pressure to follow the mandated science syllabi, where the content was being continually assessed. This factor may impede science teachers from exploring an inquiry approach. As one participant explained: *"It is not always easy to plan in the new classrooms … some of the students want some quiet worktime".* Poor acoustics, in some of the Faraday designs, was major distraction for teachers working with lower secondary students. It was inferred that noise and behaviour management might be perceived as a risk during inquiry-based activities. Multi-modal technology and/or engineering projects were observed. A range of inquiry-based approaches were evident in middle school years, consistent with the OECD's 4Cs (Barak, 2107; Davies et al., 2018; OECD, 2013b).

In some schools, groups of highly motivated students were observed. One of the key factors for creative success was directly related to what was concluded to be 'good STEM/Science teachers' with highly developed PCK. One experienced participant claimed: *"Our kids are mentored by an enthusiastic teacher … our STEM Clubs are very successful … these are usually held outside of the formal school timetable … the kids often meet during lunchtime or after school … the kids are really keen".* Extension opportunities were part of a STEM culture outside the formal disciplinary-centred upper A-Level-science. The PF-ILEs did not appear to be the major motivation for these STEM clubs. Instead, it appeared to be driven by both highly motivated students, and a highly skilled teacher who typically worked in small collaborative groups. At another school the researchers observed six lower secondary students in a small room full of robotic and 3D printing devices. The students detailed their projects. Their teacher reported: *"My kids are very much a self-selecting lot with a huge interest in robotics and applied technology ... they love getting in here and building stuff … We are really big on the STEM problem-solving … we are with the York STEM group … fantastic people with great networks … the kids are really into it!".* Visiting York, the researchers held discussions with STEM consultants. Interesting inquiry/problem solving approaches were observed (STEM Learning, 2021).

Inquiring-based pedagogies were observed or discussed at STEM school clubs that were held outside the formal curricula, reinforcing a binary approach to STEM especially in well-resourced schools. A senior participant involved in a STEM club said: *"We are really supported … you know, the inquiry STEM … the club students really love making things after school … and yes working together… also we have a fantastic teacher that makes it all happen".* The teacher explained: "*Another important focus at our school is teaching our older students to achieve [A-Level] success in sciences … at our school it is making sure our older group gets into good universities … this is central … our parents expect this".* The data suggested that parental perceptions and expectations played an important role in both the STEM club and A-Level science. One teacher claimed that: *"We have moved to an explicit instructional approach to help with examinations".* The importance of inquiry-based science was consistently linked to lower secondary contexts or primary schools. One STEM teacher stated: *"Our local schools… yes — upper primary classes are participating in the inquiry-based STEM Learning Centre model ... I know of local feeder schools are focussed on maintaining integrated STEM options… yes — for their younger kids … I suppose as* *motivation for the transition into our secondary science program … Some of the good primary teachers are thinking in terms of transition into the big school".*

In addition, some participants claimed that parental support for STEM was an important factor for student STEM engagement. This was observed in the higher socio-economic school case studies. As one teacher explained: *"At our school we have highly skilled specialist science teachers … some are super keen when it comes to a passion for the inquiry-activities … they are hooked onto the national STEM thing at York ... yes and really gaining some big international recognition online ... our students and parents are excited … the school thinks it's just fabulous … our principal — yes! All this famous online attention… it is pop star fame … success playing with robotics … creative engineering, moving things that work … it pulls everyone in … yes — all of this…well, it is providing super high-level marketing for our school … what's not to like about it?"*

When a school's online profile was investigated it was clear that a school socio-economic status influenced the depth and diverse learning across dual PCK. Students from lower to middle year secondary levels were observed working on projects in a what was a crowded storeroom during a lunch break — not an ILE. Students talked about their online profiles and STEM networks; however, none this was happening in a purposely designed PF-ILE. The teacher was central to the success. The data did not provide evidence any upper secondary examples of engineering-centred STEM, although it was listed as an accredited A-Level discipline. Observations of an overlap of engineering in some of the design and technology workshops did occur, which appeared to be facilitating skills with metal, plastic, wood constructions — very similar to the Australian context and university's ITE design and technology programs.

Didactic-centred A-Level Science

Thirdly, although the data reported a consistent bias towards a disciplinary-centred science curriculum in the upper secondary years within the PF-ILEs, and there were positive sentiments towards a broadening of the discipline centred approach. One senior science teacher claimed: "*We are very proud of our well-appointed science rooms … the aesthetics … and quiet practical".* Often these science rooms were very much extensions of specialised upper secondary science disciplines such as chemistry, physics, and biology, reinforcing the perception that the aim was to model a laboratory environment with little evidence of an integrated STEM approach.

Senior teachers made very limited references to mathematics learning and teaching — as either an interdisciplinary component of STEM, or as a specialised discipline. Observation of mathematics classes provided little evidence that his learning area was as being directly linked to PF-ILEs or integration in the broader notion of STEM as discussed by Sokolowki (2018). There is the need for further research into how mathematics is perceived within the overall STEM education construct. STEM appeared to be used as a term for science in the upper years consistent with Carter (2017) or having fun building robots in STEM clubs with 'guru' science teachers.

There were some very unambiguous responses regarding upper secondary pedagogy, for example, one teacher declared: *"Zero STEM integration … the curriculum dominates … we focus on examinations …".* Another explained: *"Our students have to pass examinations … I do not recall any industry engagement or relationship with the York's STEM Centre … the science curriculum comes first".* Another participant claimed: *"Really, there is no serious inquiry-based science happening in the upper classes".* Observations and interviews from school site visits highlighted a bias towards A-Level chemistry, physics, and biology, a focus reinforced by all the technical staff who were interviewed. High quality science laboratory-style classrooms were observed, most of PF-ILE designs were consistent with quality traditional mid-late 20th century styles and were often inclusive of novel aesthetic interpretations with more curved walls and external vistas. One participant claimed: *"Until the project [PF] … our science room designs were 1950s …".* Most of the new science classrooms were architecturally well-designed, fostering high academic expectations across disciplinary-centred science supported by experienced technicians. It appears that school pride was reflected in these builds and was linked to the overall marketing of the school. As one technician summed it up: *"My job — well it is all about the efficient running of our science prep-areas … especially, to support upper school science [i.e., chemistry, physics & biology] … I am lucky that our preparation rooms near the science rooms … we also help with all the lower school classes … it's what we do … we are always busy".*

Although, the data reported a bias towards didactic or a teacher-centred approach in upper secondary science, some group work was observed. One technician claimed: "*We see group work … students working on chemistry tasks … mostly the teachers run focussed lessons … our kids are great at working together on curriculum tasks!"* The technician disclosed collaborative work was happening but overall, the inference was the pedagogy was directed to assessment of science content and learning outcomes for examination — an explicit approach for upper secondary learning as reported by others (Beauvallet, 2014; Bell, 2015). Throughout the open conversations with participants, it became increasingly clear that the A-Level examinations and university entrance was a factor inhibiting innovative inquiry-based STEM PCK as intended by the Blair UK Government (GovEd, 2015). Yet some schools managed to promote two distinctive pedagogies, one consistent with the holism found in the OECD's 4Cs. Progressive senior leadership, excellent teachers, motivative students and supportive parents were considered key factors, with PF-ILEs being less obvious drivers. It was concluded that some school leadership teams were very clever at negotiating inquiry approaches, and A-Level science linked to the expectations around examination success and university entrance.

Digital Technology

The fourth theme reported in the data suggested that digital technologies overall occupied an instrumental role in supporting didactic learning in the upper secondary science classes, although tablets and laptop computers were used. One teacher explained: *"Our students have to purchase their own tablets".* A technician claimed: *"Digital safety and security is a real concern at our school …".* This concern was often evidenced both graphically on classroom walls and during open discussions regarding cyber safety. The science-laboratory classrooms were well-equipped, with contemporary digital technology, and standard infrastructure (e.g., gas, water, and fume hoods).

A technician emphasised: *"You know, it's really about keeping an eye on the cost of maintaining things … we are trying to replace the old tech with new flexible portable digital tech … it is really a big concern for our school — expensive and the old tech is just too hard to repair … not worth it!"*. A participants said, *"… creative problem-solving applications … and digital technologies were important in a variety tech-teaching ways … keeping this tech secure is a big challenge as it invites temptation for some … not during STEM Clubs … 3D printers and robotic kits are expensive".* A participants claimed: *"… we are supported by safe STEM networks … also sponsors like BAE [Systems]*". A STEM with digital technology (TPACK) was the exception rather than the norm.

Discussion

The discussions with 32 participants from seven English Project Faraday secondary schools elicited practical suggestions for the design of a new initial teacher education STEM learning environments.

The science technicians provided practical insights into organisational sustainability of PF-ILEs; however, it was lower secondary students who offered insight into inquiry-based STEM covering robotic engineering and digital projects facilitated by outstanding teachers.

Feedback provided by teachers provided a contextual insight into how government policies impact age appropriate PCK. It was evident that, in the schools visited in England, international benchmarking (PISA & TIMMS) dominates the upper secondary learning, which appears consistent with the upper secondary examination culture in Australia which is similarly used as a selection criterion for entrance into universities.

The implications for an ITE-STEM program, indicates that developing teachers require a thorough grounding in age-appropriate STEM-PCK and require opportunities to be mentored with a culture of enthusiasm, in flexible and durable makerspaces (ALE, 2021) that can be adapted and respond to technology and pedagogies.

Design Consultation

The literature surrounding PF-ILEs indicated extensive PF consultation (GovEd, 2015); however, the seven case studies covered in this research project suggested some aspirational designs were conceded to the financial restraints. There was wide range of design variance across schools. Collaboration between architects and senior science teachers was a positive aspect as it provided an opportunity for pedagogy to inform building designs. However, the data obtained did not report:

- Pedagogical conversations with participants and/or architects on how the PF-ILEs would engage the 16-year-old students into science.
- Discussions involving teacher induction associated with engaging the new PF-ILEs.
- Conversations covering the evaluation of the builds' influence on learning, although research recommends reflective evaluation (ALE, 2021).

This gap in the data has implications for teacher education STEM programs and professional learning which needs to include content and experiences involving holistic learning ecosystems (Imms & Kvan, 2021).

Most participants in this study consistently reinforced a sense of pride in their school's Faraday builds. Some PF-ILE's were distinctive, and the participants were very generous and open in their conversations reflecting a very positive learning culture, whether it was discipline-centred or inquiry-centred STEM.

Teacher participants were well informed about STEM-PCK and were endeavouring to facilitate a positive emotional culture consistent with research (Barratt et al., 2013; Fraser et al., 2020).

Special Learning Needs and Design

There was a design need to balance the visual aesthetics with the need for speech discrimination, with both teachers and students claiming this was an equity issue for some for students with diverse learning needs.

Overall, the spatial typology dominated the design of the ecology of the PF-ILEs. Data collected reported design gaps associated with catering for students with special learning needs, which is consistent with other researchers (Barratt et al., 2013; Fisher 2005; Fisher, 2016; Fraser et al., 2020; Imms & Kvan, 2021).

Universal design principles need to be included as part of design parameters, as well as modelling that enable accessibility regardless of pedagogy.

Factors Supporting Learning Ecosystems

The role that science technicians play in organisation sustainability is a key to facilitating both holistic learning ecosystem and specialised discipline-centred science. Technicians shared practical suggestions regarding preparing learning activities for chemistry, physics, and biology and inquiry PCK. Technicians appear to be a key factor that can enhance a science teacher's capacity to explore STEM-PCK (STEM Learning, 2021; Tytler, 2007; Tytler et al., 2008). Technicians should be included in the design process of any new build.

Technical support and material access was deemed essential to all pedagogies observed. The safe and secure storage of materials and equipment need to be located close to PF-ILEs. Flexibility and durability are essential, and consistent with current research (ALE, 2021; Barratt et al., 2013; Fisher, 2005; Imms & Kvan, 2021; OECD, 2017). Digital technology that was fixed facilitated a teacher-centred learning approach by default.

Technicians claimed that rigid school timetabling inhibited a more diverse pedagogy. The prime driver of the upper school pedagogy was the explicit need to pass science examinations (Bell, 2015).

Flexible and Durable Makerspaces

Teachers are central to interpreting and implimenting STEM-PCK, flexible and durable architectual designs facilitate a function learning planform to generate a positive self worth for teachers, students and parents, and learning outcomes. There is a potential STEM synergy with design and technology ITE, and authentic problem-solving, rather than designing school learning envrionments around traditional learning expectations (Barak, 2017; Tytler, 2007; Tytler et al., 2008).

Any new school ILE designs should accommodate diverse outcomes. Therefore, STEM and engineering projects must include a range of fabrication tools/machinery for metals, wood, plastic fabrication, and portable digital platforms. Such a design criteria should be included in makerspaces. Such processes have the potential to shift STEM education away from the neologism of STEM as science education only (Carter, 2017).

Contemporary digital platforms, such as 3D printing and engineering problem-solving promote STEM problem-solving and inquiry into durable makerspaces where a range of authentic kinaesthetic learning is woven with PCK that affords larger class sizes.

Display Spaces and Marketing

The Faraday schools were very skilled at exhibiting models and other project work. Schools had invested in professional images and informative textual information supporting STEM. The inclusion of these visual images and exhibition of project work should be incorporated into the design of any new initial teacher education makerspaces. Teacher education programs often facilitated professional engagement through focussed exhibition of ITE work. These displays are designed to inform communities about the andragogical investment required to enhance graduates with diverse pedagogical practice. In addition, such designs provide a sophisticating marketing tool for future students and industry partner engagement.

ITE Induction for Diverse Stakeholders

One of the fundamental lessons from Project Faraday was the need to provide ongoing engagement with bursars and administrators. As Bell (2015) claimed short-term reactions based on political or economic expediancy collapses the long-term goal of innovation. Therefore, given the examples in these schools, new ITE-makerspace needs to provide ongoing andragogical awareness induction to university academics. Inclusive learning environments, are evidenced-based and should not be rationalised based upon the perception of andragogical and pedagogical knowledge. The cultural reproduction of learning environments based on what non-educators or external school board members using their recollections of personal school or university days is high risk as reported by Bell (2015).

Conclusions

Although the current study did not provide data to support the Blair Government’s Project Faraday initiative with ILEs and STEM participation rates, it did highlight similar changes of contemporary STEM challenges (Australian Academy of Science, 2021; STEM Learning, 2021; Tytler, 2007; Tytler et al., 2008). Data elicited some important general design principles to inform learning ecosystem designs especially for inquiry-based and problem-solving STEM. What is essential in the design process is both the inclusion of current ILE research, and the practical insights from authentic stakeholders who will be engaging in what could be termed general makerspaces for adult learners.

Importantly, as universities within Australia and other countries are the principal providers of graduate teachers, appropriate new build offers a better fit to a negotiated design retrofit of an existing teaching space. Teacher education programs engage adult learning in early childhood, primary and secondary programs preferability in authentic social constructivist approaches. An ITE-makerspace needs to focus on the andragogical experiences of the adult learner not the year levels that they intend to teach into (STEM Learning, 2021). Flexibility needs to be a primary consideration so that a teaching and learning environment can accommodate a variety of pedagogies and new technologies (Barak, 2017).

Regardless of the quality of diverse PF-ILEs encountered in England, we concluded a need for ongoing research into professional learning for not only STEM teachers, but administrators to regain an understanding how ILEs enhance inquiry-based STEM. This study concluded that the STEM teachers interviewed were very aware of progressive age-appropriate STEM pedagogies; however, it was politicians, school bursars, administrators, and parents that needed greater understanding of the value of holistic learning ecosystems consistent with Project Faraday’s intent (GovEd, 2015). Investing in new learning ecosystems such as makerspaces needs to be planned and include progressive evaluation of the ILE as highlighted by research (ALE, 2021; Barratt et al., 2013; Fisher, 2005; Imms & Kvan, 2021; OECD, 2017). This planning must also include induction for technicians who support a range of STEM pedagogies. Well trained technicians appear to have a key role in supporting STEM/science learning.

The other important conclusion was the need for timetabling to provide access to the proposed preservice education makerspaces so adult learning can be undertaken outside of formal teaching time allocations with technical support. Authentic STEM pedagogies are facilitated by kinaesthetic engagement often within a social constructive setting (Australian Academy of Science, 2021; Barak, 2107; Tytler, 2007; Tytler et al., 2008).

Finally, ITE needs to be informed by research that includes age-appropriate context (early years to upper secondary years). Graduating teachers who experience pedagogies linked to ILEs should be able to create opportunities to question the current school learning environments and be informed about safety, risk securing flexible and durable equipment.

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