Chapter 18
Designing Rich, Evidence-Based Learning Experiences in STEM Higher Education

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Abstract Science, Technology, Engineering and Mathematics (STEM) higher education offers unique challenges and opportunities to develop effective blended learning practice. Scholarly research by STEM practitioners in designing evidence-based blended learning designs and practice is essential in its educative capacity of supporting STEM academics to reflect upon and develop their learning and teaching practices. The Griffith Sciences Blended Learning Model provided a "grass-roots" approach to developing evidence-based practice within STEM. Educational design-based research along with interviews of key innovators has provided Griffith Sciences with valuable lessons and insights which have enabled the group to progress and expand its blended learning design practices now and into the future. Informed by the range of learner-centred designs and practices explored in previous chapters, this final chapter provides nine evidence-based principles and guidelines for developing blended learning designs in STEM higher education. Although these principles have been derived from one implementation of blended learning technology and in one university for STEM higher education courses, it is tentatively proposed that these principles can support other university implementations particularly in developing ePortfolios or personal learning environments.

Keywords Design-based research · Design principles · STEM · Technology implementation · Blended learning

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C. N. Allan et al. (eds.), *Blended Learning Designs in STEM Higher Education*,
https://doi.org/10.1007/978-981-13-6982-7_18

18.1 Introduction

This book is unique in that it provides a snapshot of one university and one implementation of a new technology within a Science, Technology, Engineering and Mathematics (STEM) context. It documents the "grass-roots" initiatives of STEM practitioners and the blended learning designs that have organically grown throughout this process. This chapter is important because it sets out a series of blended learning design principles specifically focused on the STEM disciplines within Griffith University, Australia, but potentially can be adopted and adapted in many universities and in many other contexts. These principles were developed through an educational design-based research project and gathered through a series of interviews with key innovators of the Griffith Sciences Blended Learning Model and through practices and principles demonstrated in the previous chapters.

In 2015, Griffith University undertook a significant strategic change process to implement a new "Griffith Model" of learning and teaching with the purpose of increasing student engagement and employability skills through the development of contemporary pedagogies (Allan, Campbell, & Green, 2018). The intention of the change management was to develop a planned and evolving shift of learning and teaching pedagogies to support the professional mastery of students and to develop programs and courses that were conducive to developing professional mastery. In order to support this change, Griffith Sciences developed the Griffith Sciences Blended Learning Model (see Allan & Green, 2018) to provide a structure that would support and nurture the budding ideas of STEM practitioners within the context of the larger organisational shift. This chapter documents the blended learning design principles developed, tested and refined using educational design-based research through this process.

18.2 Design-Based Research

Design-based research has been cited in the literature under a number of different names, including design research, educational design research, design experiments and development research. It was originally conceived by Brown (1992) to support the development of her teaching practice and embrace the idea of involving students in the research process to become "communities of learning and interpretation, where students are given significant opportunity to take charge of their own learning" (Brown, 1992, p. 141). It is similar to action research but whereas action research is more attuned to developing personal practice, design-based research adopts a systematic and iterative approach to analyse practical problems, develop solutions, evaluate the solution in practice and determine key design principles (Herrington, Mantei, Herrington, Olney, & Ferry, 2008; Phillips, McNaught, & Kennedy, 2012; Reeves, 2000). Design-based research aims to "provide insight into learning in real-world contexts" with the goal to research, design and improve our pedagogical practice (Joseph, 2004, p. 235).

> Such research, based strongly on prior research and theory and carried out in educational settings, seek to trace the evolution of learning in complex, messy classrooms and schools, test and build theories of teaching and learning, and produce instructional tools that survive the challenges of everyday practice. (Shavelson, Phillips, Towne, & Feuer, 2003, p. 25)

Design-based research projects are appropriate in a university context and can involve teams that include educational designers, researchers and teachers implementing the project (Brown & Edelson, 2003; Cobb, 2000). The purpose is not to determine whether one process is better than another, it is to iteratively refine and develop a solution through testing and reflection to improve the educational environment (Reeves, 2006). The general process followed in design-based research includes: identifying an issue, challenge or problem within the educational context; discuss with stakeholders and undertake research to come up with a solution to said problem; and finally, to test the problem's solution, refine it and extend it over a number of iterations (DiSessa & Cobb, 2004).

18.2.1 Phases in Design-Based Research

In the Griffith Sciences Blended Learning Model, we have adopted an approach based on the four-phase model of design-based research as developed by Reeves (2006, p. 59). The four phases include:

1. Analysis of practical problems by researchers and practitioners in collaboration;
2. Development of solutions informed by existing design principles and technological innovations;
3. Iterative cycle of testing and refinement of solutions in practice; and
4. Reflection to produce a series of design-based principles relevant to the specific context to resolve the problem.

More details of the Griffith Sciences Blended Learning Model (the design-based approach adopted) can be found in the introduction of this book.

18.2.2 Why Are Design Principles in STEM and Blended Learning Necessary?

There are a number of issues and barriers to implementing change in STEM disciplines. Lack of time (Brownell & Tanner, 2012; Dancy & Henderson, 2010), lack of training (Brownell & Tanner, 2012), lack of faculty and/or administrative support (Foote, Knaub, Henderson, Dancy, & Beichner, 2016), lack of incentives and working in a top-down decision-making culture in STEM (Hains-Wesson & Tytler,

2015) can all be barriers to successful change. The research suggests that although there is a wealth of knowledge of evidence-based practices in STEM, much of this evidence is not being used by large numbers of STEM teachers (Froyd et al., 2017; Khatri et al., 2016). It is argued that this is partly because relevant literature in STEM higher education is not necessarily accessible, as the literature is scattered in disciplines and journals outside of STEM (Borrego & Henderson, 2014) and because, in STEM disciplines, many decisions regarding appropriate teaching strategies are not determined based on evidence but on anecdotes, instinct or personal prejudice (Overton & Johnson, 2016). STEM culture is often considered to be an underlying barrier for the lack of sustainable success with learning and teaching change (Brownell & Tanner, 2012; Landrum, Viskupic, Shadle, & Bullock, 2017).

18.2.3 Design Principles

A number of research projects have developed design principles (Downing, 2015; Herrington, 2006; Guardia, Maina, & Sangra, 2013; Herrington, Herrington, & Mantei, 2009; are just some examples). Design principles have been developed for mobile learning (Herrington, Herrington, & Mantei, 2009), authentic and situated learning (Herrington, 2006), MOOCs (Guardia et al., 2013) and applied learning design (Downing, 2015), amongst other areas. Design principles have also been developed within the STEM disciplines. Overton and Johnson (2016) suggested eight evidence-based design principles for learning and teaching within STEM: avoid cognitive overload; be careful what you measure; ensure students are prepared for laboratory and field; prepare students to learn in lectures; embrace flipping; ensure active learning; make it authentic; and consider the implications of technology. The Griffith Sciences Blended Learning Model uses this set of principles to guide its educational design-based research project(s).

Also very relevant, from the blended learning perspective, was McGee and Reis's (2012) article on blended course design. In their meta-analysis of blended course design, they found a number of best practices in blended learning—within the design process, pedagogical strategies, classroom and online technology utilisation, assessment strategies and course implementation and student readiness. Although not expressly stated as design principles, they found a number of best practices that apply to blended learning design. Some best practices include:

- Design process—defining course objectives before designing course activities, assignments and assessments; writing objectives from the student perspective; alignment of activities, assignments and assessment; blended courses most successful when challenging and engaging online learning activities are used to complement face-to-face activities.
- Pedagogical strategies—there must be integration between classroom and online learning experiences; varied interactivity and prompt feedback are key to student engagement in blended courses; active learning is integral for student engagement;

blended courses effective for metacognition; process driven; product and project orientated.
- Classroom and online technology—utilising the technology in the classroom as well as online; alignment with instructional strategies is key; focus on technology to support learning (means to a pedagogical end).
- Assessment strategies—distinction between collaborative versus cooperative assessment; blended designs tend to revert to traditional assessment modes whilst encouraging non-traditional instructional strategies.
- Course implementation and student readiness—communication of the blended design, expectation and process is key for student success; students do best when they are encouraged to be independent learners; provide clear and accessible support for online technology; clear instructions, manageable assignments and relevant activities support students to take responsibility of their learning outside of class and be prepared to participate in class; providing periodic student course evaluations (McGee & Reis, 2012).

Quality Matters (QM), an internationally recognised peer review organisation, also provides guidelines in the form of a rubric to aid designing blended learning courses. According to Legon (2015), the quality standards within the QM rubric follow a number of clusters that articulate their intended impact. Legon (2015) states that their best practice recommendations are based on eight clusters or standards: clarity of purpose; ease of use; course alignment; learner engagement; accessibility; knowledge acquisition; compliance; and learner support.

18.2.4 Design Principles and PebblePad

Although the design-based research undertaken was looking at blended learning designs, it must be noted that this project was undertaken as a result of the university purchasing new software, PebblePad, to support blended learning. Even though the design principles developed are focused on blended learning principles and do not necessary require a specific system, such as PebblePad to implement, it should be noted that PebblePad has particular tools and affordances that provided opportunities for increased learning opportunities within the STEM disciplines. The Griffith Sciences were particularly excited by the learner/learning-centred aspects, as suggested in the quote below, in the hope it would help transform the use of blended learning in our STEM programs/courses.

> PebblePad provides a space where learning can take place that is personal, eclectic and idiosyncratic and so we have chosen to refer to it as a personal learning space (Sutherland, Brotchie, & Chesney, 2011, p. 4).

The developers of PebblePad have also provided some relevant design principles to guide the creation of tasks within a personal learning environment. Sutherland, Brotchie and Chesney (2011, p. 6) suggest that PebblePad will add value to learning in activities that guide users through acts like planning and reflecting, promote improvement via timely feedback, encourage sharing, reviewing and peer support, engage others outside normal teaching context, value a variety of evidence; and recognise learning from experience and over time. They expound a set of principles for PebblePad: supports personal learning; offers a safe and private place which is owned and controlled by the user; is multi-purpose but purposeful; supports learning wherever it happens, whenever it happens; helps to surface and scaffold the process of learning; is underpinned, and informed, by a reflective structure; gets people talking and helps users construct their narratives; and can accompany learners throughout their lives and across all their activities.

18.3 Who Are Involved in the Griffith Sciences Blended Learning Model?

The design principles were developed through initiatives within the Griffith Sciences Blended Learning Model. Thirty-three projects were implemented in 2017 and a further twenty-three in 2018. Many of these projects were evaluated and documented in this book. There were projects in all four (at the time) Griffith Sciences schools (and all STEM disciplines)—Engineering (13 projects), Natural Sciences (11 projects), Environment (four projects) and Information Communication Technologies (five projects). There were a wide variety of projects with program and course-based initiatives ranging from embedding employability skills into the curriculum (across multiple courses), to supporting group projects, to setting up field trips, industry visits and to document final projects and milestones. Table 18.1 provides a breakdown of the projects in 2017 including class sizes, fields of study and uses within STEM disciplines.

The project included an overarching ethics application that covered a variety of different data points depending on the nature of the project. Each project collected their own data depending on their needs and was able to collect survey data (institutional survey or individual), focus groups, interviews, assets in the learning management system (Blackboard) and within PebblePad as well as student evaluation of course data.

18.4 Findings from the Blended Learning in STEM Higher Education—Griffith Sciences Blended Learning Model

The following “tentative” conclusions and design principles have been derived from a review of each of the individual chapters along with interviews with ten key innovators who were involved in the Griffith Sciences Blended Learning Model Expression of Interest process and feature in many of the chapters in this book. These principles

Table 18.1 Uses for PebblePad across the schools in Griffith Sciences throughout 2017

School	Engineering	Natural sciences	I.T.	Environment
No. of initiatives	13	11	5	4
No of students	More than 1000 students	More than 1300 students	More than 700 students	Around 80 students
Smallest/largest class size	7/306	21/479	31/331	13/42
Fields of study	Practical electronics, engineering science, international engineering practice, engineering design practice, project management principles and others	Biotechniques laboratory, biological systems, chemistry, mathematics, flight procedures, physics, forensics and the professional practice in science (capstone) course	Human computer interaction, information management, IT foundations, routing and switching and network security	Studio work, as part of their geographic systems course and also part of their practicum
Uses	Employability ×4, Reflection ×3, Authentic tasks, Industry field trip—interaction with industry, Group project ×2, Milestones and final project × 2, Laboratories ×2 (laboratory reports, laboratory results)	Employability ×3, Laboratory skills ×2 Laboratory reflection and Laboratory book, Connect Laboratories across course, Scaffolded activities, Reflection on flight procedures	Employability ×2, ePortfolio × 2, Reflection, Week-to-week activities ×, Feedback, Group collaboration ×2, Peer assessment, Milestones	Employability ×2, Reflection ×2, Week-to-week activities, Linked with Planning PLUS

are not considered to be necessarily generalisable across other institutions (as they are developed in one specific context for one cohort of initiatives and generally using one technology) but are potentially valuable as an initial discussion point for blended learning design in STEM disciplines. Further studies would be valuable to determine which principles are robust enough to transfer to other institutions and other disciplines. Table 18.2 provides an overview of the design principles, key literature and key features. Further details on the design principles are provided afterwards.

18.4.1 Design Principle 1: Quality Blended Learning in STEM Starts with a Coordinated and Ongoing Series of Informal Professional Learning, Support and Dissemination Strategies

It is not enough to provide one off training sessions if you want to embed a new technology within STEM. Ad hoc professional development activities provide an avenue for developing knowledge and skills. These activities are an important part of a professional learning process (in disseminating curriculum and pedagogy) but they are not the only element that is needed. The Griffith Sciences Blended Learning Model is a framework that can support and guide the development of projects embedding and sustaining a new learning technology. The model incorporated strategies from each of the four categories of change strategies, advocated by Borrego and Henderson (2014): (1) disseminating curriculum and pedagogy, (2) developing reflective teachers, (3) enacting policy and (4) developing shared vision (Henderson, Beach, & Finkelstein, 2011; Borrego & Henderson, 2014) and a four-phase design-based methodology inspired by Reeves (2006). This model has demonstrated a successful approach to implementing a learning technology by funding "grass-roots" initiatives in the Sciences (Allan, Campbell, & Green, 2018).

The model uses a combination of strategies to support and guide academics. Our research tentatively suggests that a model that incorporates the following elements may be successful when implementing technology in the Sciences (although further research would be valuable to further test this):

- Use a ground-up approach—ensure ideas are generated not from a top-down agenda but through listening to the ideas of Science early adopters and innovators;
- Focus on purpose in the early stages of adoption;
- Develop learning designs to articulate the learning process but also as a tool for future reflection and development and showcasing to others;
- Provide ongoing support and training activities that are focused on the needs of the innovators;
- Create a community of practice with the goals of sharing ideas, resources, lessons learned and building organisational knowledge within the Sciences; and
- Embed opportunities for reflection and evaluation of the projects that are developed.

Table 18.2 Design principles for blended learning designs in STEM higher education

	Design principles	Key literature	Key features	Relevant chapters
1	Quality blended learning in STEM starts with a coordinated and ongoing series of informal professional learning, support and dissemination strategies	Borrego and Henderson (2014) Henderson, Beach, and Finkelstein (2011)	Consider a ground-up approach Focus on purpose in the early stages of adoption Develop learning designs Provide focused ongoing support and training Create a community of practice Embed opportunities for reflection and evaluation of the projects	The overall process of professional learning is outlined in the introduction. Chapter 2 provides the university context and many of the initiatives developed throughout the university. Chapter 3 describes the learning design focus used within the initiatives. Chapter 4 discusses the community of practice. Chapter 5 describes a process for developing professional practice in L&T within STEM disciplines
2	Use purposefully designed resources and faded scaffolding to manage students' cognitive load	Overton and Johnson (2016) Sweller (2010) Kirschner, Sweller, and Clark (2006) Vygotsky (1978)	Purposefully designed templates (including clear step-by-step instructions) used to manage cognitive load by simplifying the process Use of consistent templates throughout a course or program with reducing levels of support/hints (faded scaffolding) to manage cognitive load Templates that incorporate faded scaffolding throughout the course or program Visuals, video, notes and worked examples used to simplify concepts	Chapters 11, 12, 15 and 17
3	An ongoing "weekly" laboratory workbook or learning journal has potential for engaging students with the scientific process and helping them to think like an expert in their respective discipline	Roberts, Maor, and Herrington (2016) Kober (2015) Sutherland et al. (2011)	Digital notebook viewable by lecturer throughout semester Emulate an expert in the field Clearly and overtly attach incentive/value through marks or direct link to other assessment	Chapters 5, 12, 13 and 16

(continued)

Table 18.2 (continued)

	Design principles	Key literature	Key features	Relevant chapters
4	Develop content knowledge via practising and reflecting on real or simulated activities (i.e. laboratories, field experiences, WIL, simulations)	Wieman (2017) Felder and Brent (2016) Overton and Johnson (2016) Rodgers (2002)	Embed content into real or simulated activities and allow practice Content knowledge developed through doing and reflection Reflection is the bridge between theoretical concepts and real-world tasks Need to find a way to help Science students appreciate the value of reflection Explicitly teach reflective process and scaffold reflection	Chapters 9, 10, 11, 12, 13, 14, 16, 17
5	Embed explicit opportunities for students to develop, understand and articulate their employability skills	Rich (2016) Wingate (2006) Yorke and Knight (2006)	Purposefully embed employability activities throughout a program Clearly and overtly attach value through marking employability activities Bite-sized activities culminating in comprehensive employability resource (collection or portfolio)	Chapters 6, 7, 9, 10, 11, 17
6	Embed opportunities for ongoing feedback and feedforward to scaffold expert thinking	Wieman (2017) Kober (2015) McGee and Reis (2012) Hattie and Timperley (2007) Nicol and Macfarlane-Dick (2006)	The ability to auto-submit, at the beginning of a task, in PebblePad, provides an excellent opportunity for providing feedforward and support Feedforward used to scaffold students learning and reduce misconceptions Stagger assessment tasks and use feedback to generate deeper learning	Chapters 5, 10, 12, 15

(continued)

Table 18.2 (continued)

	Design principles	Key literature	Key features	Relevant chapters
7	Hyflex mode has potential for developing flexible STEM environments (particularly ones with both f2f and fully online students)	Taylor and Newton (2013) Beatty (2006)	Potential value in supporting programs that have both face-to-face and online cohorts Create tasks that connect online and face-to-face students	Chapters 7, 12 (specific focus in Chap. 12)
8	Focus on program-wide learning, teaching and assessment	Roberts (2018) Eynon and Gambino (2017) Roberts et al. (2016)	Use faded scaffolding, where appropriate, to develop increased skills throughout a program Embed bite-sized employability tasks throughout a program in targeted courses Link tasks into a final collection or portfolio for final synthesis and reflection Set expectations early, particularly answer the questions, why and how they will use portfolio	Chapters 6, 9, 10, 11, 17
9	Build activities that allow students to learn with and from others	National Academies of Sciences (2018) Eynon and Gambino (2017) Vygotsky (1978)	Use technology to support collaboration in real time and asynchronously Be aware of technology limitations and design tasks accordingly Peer mentoring is powerful for supporting reflection, evaluation and development of concepts	Chapters 9, 12, 13, 16

18.4.2 Design Principle 2: Use Purposefully Designed Resources and Faded Scaffolding to Manage Students' Cognitive Load

In many of the blended learning designs, technology was used purposefully to design tasks that scaffold and support students developing their understanding of conceptual knowledge. In many science-based courses, there is a high cognitive load attached to laboratory work (Sweller, 2010) with students expected to complete multiple calculations and then develop a substantial laboratory report. To reduce the cognitive load, templates were used in many of the projects to guide students through a scientific, engineering or computing process. These templates often included "step-by-step instructions that guided students through activities and supported proper scaffolding" (interview). They were broken down into "meaningful chunks of content" (interview), which were sequenced to support the students understanding of the topic. Notes, questions and worked examples were often provided to advance the student's knowledge of the topic. This process aligned with the design principles recommended by Overton and Johnson (2016). These resources incorporated visuals, pictures and videos to simplify concepts. In some instances, reflective questions were incorporated to provide an opportunity for students to critically assess the steps they completed. A template was created for each experiment and included questions like "what did you learn? How might you use these skills in the future? How confident are you?"

Purposefully designed templates or pro formas were used repeatedly to simplify processes, allow the student an opportunity to practise and help manage the cognitive load in physics, biology, engineering and chemistry. Creating a laboratory or reflective template, with detailed instructions, the first-time students attempted a particular process tended to support knowledge acquisition. Using the same template with hints and tips in subsequent activities reduced student anxiety and helped students manage their cognitive load (Kirscher, Sweller, & Clark, 2006). As was suggested in one of the interviews, the iterative use of scaffolded templates "enabled students to quickly focus their attention on key steps in the process" potentially reducing their cognitive load. At the beginning the template for the laboratory project or other task would be full of hints and tips, reflective questions and detailed instructions (i.e. more scaffolding). This detailed scaffolding gives them structure and guidance for later work (Vygotsky, 1978). In future iterations, the templates were often simplified, with much of the scaffolding and support reduced or "faded" out of the template. Items such as prompt questions, exemplars, hints and tips would be removed "as students [became] more familiar and adept" at conducting laboratory work or critical reflection. The scaffolding would be gradually removed or "faded" so that in later laboratories the student would have to conduct the activities with their own thinking. One of the challenges was to develop the right amount of hints and to determine the right level of fading for each iteration. This is an important consideration in determining the appropriate cognitive load for students.

In three of the initiatives, faded scaffolding occurred program-wide. Intensive support was provided in earlier (first-year) courses and then faded out through the middle years with no (or limited) support provided in the final course/s. This was considered important in developing the skills and reflective practice of emerging scientists. The templates and embedded support were used over a number of courses and years to build a particular skill. It was theorised that the use of the same template over a series of courses would "boost students" confidence to complete tasks successfully" and minimise the cognitive load of learning new approaches in each year. This programmatic view was hoped to instil a confidence in each student's ability to complete tasks, such as laboratory work, by the end of their program. By providing focused and purposeful support in the early instances and gradually fading or removing this support, it was hoped that students would see the linkage between certain skills and processes and therefore build their skills over an extended period of time (instead of just within each individual course). The early results have shown that although students have not necessarily found it easier to engage with the templates in subsequent trimesters, they have engaged with them more comprehensively than they did in the early trimesters/years.

18.4.3 Design Principle 3: An Ongoing "Weekly" Laboratory Workbook or Learning Journal Has Potential for Engaging Students with the Scientific Process and Helping Them to Think like an Expert in Their Respective Discipline (i.e. to Think like a Scientist, Engineer or Technologist)

One of the strategies that was used across a wide variety of STEM courses was an ongoing "weekly" laboratory workbook or learning journal. The idea was for students to complete laboratory or other practical STEM-related tasks on a regular (weekly) basis that not only was a record of progress but also built into a continual piece of work rather than a series of short unrelated activities which helped students create appropriate habits of mind (Roberts et al., 2016). The workbooks and journals were developed in different courses and were used for a variety of purposes, including: as a weekly notebook or electronic version of their notes, for weekly reflection; as a starting point for revision; as a summary of key points and concepts; as part of weekly course evaluation and to support laboratory activities and reflection. They were used to help students understand the processes used within a real environment and helped them to think and act in a manner designed to emulate an expert in the field (Kober, 2015). As one interviewee suggested "I like the fact that what they're doing is all about building their skills, their ability to think like a scientist … but also that the tasks themselves are using real equipment, modern equipment, trying to develop their ideas of how to do this, and then learn the knowledge through that". PebblePad enabled the surfacing of the processes and practices (Sutherland et al., 2011) that helped to emulate scientific thinking in digital workbooks. An assumption of many of the initiatives was that the students want an authentic experience that is basically showing them what it is like to be in that profession. The digital nature of the workbook allowed the students to include a variety of resources, not necessarily easily able to be included in a written notebook, including images, photographs of equipment and video. A key aspect of the PebblePad workbook was that students could submit their work at the beginning of the course and then continue working in the workbook with all the new ideas and items automatically updated for the teaching team to see and monitor students' progress. The fact that the teaching team was able to view the ongoing work and provide feedback (individually or to the group), helped promote the concepts of students continuously working and not waiting to the last moment to complete the assessment task.

In each initiative, it was important to clearly and overtly attach value to the tasks, activities and learning associated with the journal or workbook. It could be argued that students needed to see a value in using the blended learning activity—either directly, through a mark, or indirectly, via an obvious link to other assessment. The most obvious form of incentive used was marks, sometimes provided each week (although this created a significant marking expectation particularly in large courses) but often provided as an overall mark. Other strategies used to incentivise the task included: providing ongoing feedback, using the journal or workbook to prepare students for a large summative assessment (in one example, a design workbook was used to prepare for an oral presentation and in another, weekly tasks demonstrated skills that needed to be used in a final assessment task); and using the notes as part of a quiz or exam.

18.4.4 Design Principle 4: Develop Content Knowledge Via Practising and Reflecting on Real or Simulated Activities (i.e. Laboratories, Field Experiences, WIL, Simulations)

Design principle four is directly connected to principle three as one of the primary strategies or tools used to develop principle four is the laboratory workbook or learning journal. Many of the sciences subjects involved a requirement for students to comprehend a "lot of information" or content knowledge. One of the strategies developed to support the learning of content was to embed the content into real or simulated activities (such as laboratories, field experiences, work integrated learning and simulations) and allow students to practise these real tasks whilst picking up the content knowledge via doing and reflecting (Rodgers, 2002; Overton & Johnson, 2016). Teachers found that by embedding the content into practical tasks, they were able to cover more content in a shorter space of time; students were able to make more sense of the content because they had a "process to hang it off"; and it "enabled visibility of thinking" or "thinking like a scientist" or what Wieman (2017) refers to as "deliberate practice". As one academic stated "they're not just having to remember something, they're actually having to think about it, do something with it, play with it" and another academic noted "it made them think about their performance or the actual task rather than just doing the task mindlessly … it helped to provide the theoretical aspects of the course as you get to practise what you learn".

Developing real tasks was a fundamental strategy used in many of the STEM initiatives. The most common real strategies included: developing design briefs for real projects such as an engineering design challenge (based on the Engineers Without Borders project); or a real-world IT partnership teaming with a local theme park; getting students to undertake and design their own lab experiments in physics and biology to demonstrate basic skills of data analysis, data presentation and group collaboration, analysis and discussion; laboratory experiments to investigate a criminal case in forensics where students were given different samples from a crime scene and they analysed each of the samples to solve the case; and work integrated learning. Simulation was also used to allow students to practise real skills in a simulated environment, an environment free from the pressures and dangers of the real-world environment. In all these scenarios, students were able to practise skills, often multiple times, and reflect on these skills whilst becoming aware of concepts through practice and reflection.

Reflection on practice, before practice and after practice was an important aspect of connecting the theory to the activity. Reflection was used as a "bridge between theoretical concepts and real-world tasks". Reflection helped students to identify the skills they had developed and practised in the laboratory (or real world) and consider why these skills were important whilst placing these in the context of future work. The reflective practice helped students to "integrate theoretical knowledge with practical application". It must be noted, however, that reflection is not necessarily a natural fit for STEM students. One of the experiences noted was that these science students did not necessarily understand or appreciate the value of reflection and were not used to writing in a reflective manner. To develop better reflective practice amongst science students, it was important to explicitly teach the reflective process and to scaffold and support reflection throughout the program. Some tips for critical reflection are provided below as a starting guideline with the expectation that more detailed study needs to go into this particular area of research.

Tips for critical reflection in STEM:

- Use prompt questions to stimulate critical reflections;
- Provide an opportunity to embed artefacts alongside reflective text;
- Do not use exemplars in early, foundational tasks (attempt to avoid academic misconduct) but use specific exemplars for more complex tasks;
- Provide a welcome landing page on each workbook with instructions on how to use the workbook and what was required;
- Include a self-assessment tool so that students can check their standard of completion (in later iterations);
- Set time frames, expectations and amount of time carefully and explicitly; and
- Provide signposting and explicit identification of the connections between knowledge, tasks, assessment and student learning outcomes.

18.4.5 Design Principle 5: Embed Explicit Opportunities for Students to Develop, Understand and Articulate Their Employability Skills

Griffith Sciences has had a focus on developing the employability of its graduates for several years with a particular focus on extra-curricular activities. The limitations of a purely extra-curricular approach were recognised—in particular the notion that students have many competing demands on their time, and it can be difficult for them to prioritise personal and career development learning (Rich, 2016); and the notion that the students who "need it the least" are the ones most likely to opt-in to this type of extra-curricular program (Wingate, 2006). It was further recognised that, like discipline-specific skills and content, employability concepts are complex, and development of these skills must be scaffolded across the course of the degree program and aligned to the student life cycle. Students need time to understand what they are learning, to judge what they have achieved and to see how to improve (Yorke & Knight, 2006).

One of the planned initiatives was therefore to embed employability skills in targeted courses to promote a "program-level approach to employability" that allowed for both vertical and horizontal alignments of employability-based learning. Vertical alignment ensures students have multiple opportunities to practise their skills across the course of their degree; and horizontal alignment ensures they have access to a diverse range of employability-based learning and assessment at any given point within their degree. The embedded approach has demonstrated the value of developing employability skills throughout a program and by "clearly and overtly" attaching value to these tasks, through assigned learning outcomes, assessment and attaching grades to these tasks.

To achieve this, an "employability toolkit" was developed in PebblePad that included a series of "bite-sized", "interactive online modules" that were embedded in targeted courses across a variety of programs. These modules included a combination of "detailed instructional information" along with "information rich resources" that help students develop and reflect upon their skills and knowledge prior to an experience and opportunities to reflect upon this experience afterwards. By embedding these employability activities throughout a program, students had the opportunity to develop and reflect upon their professional identity and, at the same time, collect ideas, thoughts and projects that can be used to showcase their experiences and skills as a professional. This curation of "evidence" is an important factor in employability pedagogy as it allows students to clearly align their experiences and specific skills to the expectations of employers within their specific industry, and it further provides an opportunity for students to track their development across the course of their degree program.

The flexibility of PebblePad, and the use of a series of online modules to deliver employability-based learning and assessment, addresses another important consideration if an embedded employability initiative is to be successful. That is, that the task must not only be embedded, it must also have a "natural fit" with the existing content of a specific course. Employability-based learning that has little or no relevance to the rest of the course is likely to be perceived by students as a "bolt-on" model of employability, which will diminish the perceived value derived from "embedding" the task. The ability to adapt individual modules within PebblePad to suit a diverse range of discipline-specific contexts allows for authentic assessments with clear links to the students' anticipated future career.

The approach to embedding employability throughout programs in the Sciences Group factors each of these considerations into account. Employability-based learning initiatives are therefore: embedded (assessed); integrated with the course content; scaffolded (from first to final year); evidenced (by the student) and aligned (throughout the program and at any given point in time).

18.4.6 Design Principle 6: Embed Opportunities for Ongoing Feedback and Feedforward to Scaffold Expert Thinking

One of the guiding principles that was used in the Griffith Sciences Blended Model to determine the suitability and applicability of PebblePad in a learning and teaching task was how the academic would provide feedback and feedforward to students. In initial design conversations, each initiative needed to provide information regarding how they intended to monitor students' progress, whether they intended to provide feedback and whether the PebblePad task was going to be marked (see Fig. 18.1). If the initiative did not involve monitoring or feedback, then further conversation occurred to determine whether the software was considered to be the most appropriate. After completing this design-based research, one of our findings was that it would be beneficial to add a further section to this initial design document to include: whether academics intend to obtain feedback from students regarding the course. Three initiatives included feedback questions within their templates and design activities to collect information on "what the muddiest point of an activity was", or "what activities were working and what were not" and also to gather information on which topics were more interesting. The opportunity to provide feedback to course convenors had value in several initiatives.

What will the teaching team be doing with this activity?

This section will assist in configuring the ATLAS workspace and get you thinking about what sessional resources you may need to complete this activity.

- ***Monitored*** *- will the teaching team being viewing the progress of the students during the activity or is this activity an opportunity for the students to collate and record their work in preparation for a future learning activity?*
- ***Feedback*** *- will students receive feedback on their work either during the activity or at the conclusion or not at all?*
- ***Marked*** *- will the students receive a mark for this activity?*

Monitored	Yes	No
Feedback	provided to students	not provided to students
Marked	yes	no

Fig. 18.1 Extract from the Griffith Sciences Blended Learning Model Professional development workbook that articulates what the teaching team will be doing in a chosen activity

A significant benefit (and challenge) of using PebblePad was the ability to get students to submit work (or auto-submit) at the beginning of a task or project and to view the work (and provide timely feedback) throughout the trimester. Prompt feedback is considered essential for student engagement in blended learning design (McGee & Reis, 2012). PebblePad's auto-submit function provided academics with an excellent opportunity to see "how a student is tracking". The tracking of student work was done formally and informally (in class and outside) to support laboratory experiments, studio work and design briefs. Academics were able to view student work throughout the task and provide feedback (individually and to the group), to stop misconceptions early in a process, to provide more advice (where needed and appropriate), to provide further clarification on specific design decisions, skills or strategies and to scaffold student learning throughout a project (Nicol & Macfarlane-Dick, 2006). As was suggested by one academic "if you can see work in progress, then you can give some sort of helpful guidance along the way" and support students in developing their ability to think like an expert. It was also very important to support students who had misread the question and needed to be brought back on track.

Providing opportunities for formative and summative assessment was important. The use of formative assessment was used in the early stages of creation. Feedback on this task was often used to build or develop skills and processes that were used in later assessment tasks (Hattie & Timperley, 2007). Feedback from staff, and in some instances peer feedback, was used to "stimulate and support deeper learning". A number of the initiatives staggered the assessment thus splitting the assignment into different pieces or "milestones" that were connected and provided formative feedback and feedforward on early tasks to support the final summative assessment. In one example, an engineering design task, adding an early opportunity for feedback made "a real difference to the stage two design briefs" that were submitted later in the trimester.

18.4.7 Design Principle 7: The Hyflex Mode Has Potential for Developing Flexible STEM Environments (Particularly Ones with Both Face-to-Face and Fully Online Students

One of the initiatives focused on using the Hyflex (hybrid flexible) model (see Beatty, 2006). It was found that students appreciate the opportunity to choose their type of participation in a course. They like the opportunity to participate in face-to-face activities and online delivery. The Hyflex methodology allowed us to ensure that students were given opportunities to succeed, that they are "equally treated—online or in person" and that there was alignment of learning outcomes, resources and assessment for students who learn online and for those students learn in person. A key learning for online students was to make sure that students felt connected and that they did not fall behind in their learning and assessment. Design principles three and six were particularly useful in supporting these objectives.

It must be noted that we had only one initiative that investigated the Hyflex mode, but the premise showed real potential. It is an area where Griffith Sciences think that STEM environments (which utilise a mixed-mode approach) could benefit from further research.

18.4.8 Design Principle 8: Focus on Program-Wide Learning, Teaching and Assessment

This design principle is linked directly with design principle five and in many instances design principle two. One of the strategic advantages of using a tool such as PebblePad is that it is owned by the individual and therefore can be used throughout a program and onwards (instead of just within an individual course). The use of ePortfolios programmatically is supported by the literature (Eynon & Gambino, 2017; Roberts et al., 2016). The programmatic approach was used in STEM to support connections between tasks and courses, particularly in employability, but also in areas such as reflection and developing specific skills (such as laboratory skills). As suggested by one interviewee, the programmatic approach also helped "support students to establish connections linking theory and practice across the student life cycle" as also suggested by Eynon and Gambino (2017). The idea of utilising program-wide learning, teaching and assessment helps students see the "overarching type of thinking" associated with the STEM discipline instead of just having a "course-by-course" mentality. Some of the initiatives scaffolded reflective learning across the entire program providing faded scaffolding to support the development of ideas and experiences whilst reducing the support and scaffolding in later years.

In embedding employability (principle five), an attempt was made to weave employability tasks throughout a program using employability as a thread running through the centre of key "targeted" courses. The Engineering PLUS initiative was a good example of embedding small tasks into a number of courses to build towards an overarching understanding of the skills, attributes and knowledge necessary to be more employable in engineering. In the Graduate Diploma of Clinical Physiology, a portfolio was used to link reflection and workplace experience to showcase the learning and improvement made over a series of courses. In this initiative, individual pieces of assessment were delivered across multiple courses but designed to be linked together "holistically" as part of a culminating portfolio in the final course of the program.

One of the tips for program-wide initiatives is to set students' expectations early. It was seen as "absolutely critical" to set the expectations and clear instructions for why and how the students will be using the technology and why it is important for them. This is particularly relevant for ePortfolio use as there are many purposes for an ePortfolio and it is important that students are aware of what the purpose of the ePortfolio is (i.e. integrative/learning or professional/presentation), who is going to be viewing it and why they are viewing it. This is particularly crucial in early courses to set an appropriate stage for later tasks and use of the technology as well as help students understand the types of items to be included or what not to include.

18.4.9 Design Principle 9: Build Activities that Allow Students to Learn with, and from Others

Technology was often able to provide a connection between students and promote communication and collaboration (Eynon & Gambino, 2017). This was also possible in mixed-mode teaching where collaboration and communication were designed between groups of face-to-face students, groups of online students and groups which had a combination of students from both groups. In biology, we saw a good example of students using laboratory technology (microscopes with tablet devices attached) that enabled multiple students to view biological specimens together in an environment that allowed them to discuss their findings in real time and then use an online journal to reflect upon their findings after the laboratory. In engineering, an online scoping document was used to support students developing initial ideas for a design project that they would showcase as an oral presentation. Students were able to use a collaborative document to generate ideas and to work together before presenting as a group. In this instance, the groups had some difficulties because the technology did not allow students to access the resource when they needed to (as it would often lock when a student was using it and then sometimes it would not unlock when the student stopped using it). This caused frustration for other students which lowered some of the value of the task. In later iterations, students started using Google Docs instead of the PebblePad template as it allowed multiple people to work simultaneously.

Peer assessment and peer mentoring were also used effectively to support STEM learning. In an ICT course, it allowed students to assess other students' work, to understand the importance of the learning outcomes, to review other people's work and to evaluate their own work (using peer feedback and evaluating the work of others). The academics who used peer assessment suggest that it had high participation where it was implemented effectively (this is based on anecdotal feedback provided in the interviews; more research would be valuable to test these assumptions in future iterations). Peer assessment was particularly valuable in the Hyflex mode of delivery. The use of technology was used to support peer mentoring and feedback between the face-to-face and online student cohorts. This allowed students to work together in groups and provide peer feedback even when they were geographically disparate. This was considered important in breaking down the social isolation that is sometimes prevalent in online courses.

18.5 Conclusion

The Griffith Sciences Blended Learning Model was a project undertaken in order to enhance the quality of learning and teaching in STEM disciplines. To ensure the future success incorporating the new PebblePad technology, Griffith Sciences funded "grass-roots" initiatives in STEM disciplines, developed learning designs, created case studies and developed a series of evidence-based learning design principles to guide future practice. The project determined nine key principles for blended learning designs in STEM higher education:

1. quality blended learning in STEM starts with a coordinated and ongoing series of informal professional learning, support and dissemination strategies;
2. use purposefully designed resources and faded scaffolding to manage students' cognitive load;
3. an ongoing "weekly" laboratory workbook or learning journal has potential for engaging students with the scientific process and helping them to think like an expert in their respective discipline;
4. develop content knowledge and critical thinking skills via practising and reflecting on real or simulated activities;
5. embed explicit opportunities for students to develop, understand and articulate their employability skills;
6. embed opportunities for ongoing feedback and feedforward to scaffold expert thinking;
7. the Hyflex mode has potential for developing flexible STEM environments (particularly ones with both face-to-face and fully online cohorts);
8. focus on program-wide learning, teaching and assessment; and
9. build activities that allow students to learn with, and from others.

Moving forward, Smith and Hill (2018) not only recommend broadening the research base for blended learning research but also acknowledge its importance, including recognising the role that staff play in the adoption of technologies. Targeted funded initiatives such as the Griffith Sciences Blended Learning Model have facilitated the development of communities of practice (Wenger, McDermott, & Snyder, 2002) to support STEM practitioners in developing effective blended learning practices. It is hoped that these design principles can be used by other universities for a variety of STEM projects. Although this initiative focused specifically on one university and one specific use of technology, it would be reasonable to consider these principles valuable for a variety of applications within the STEM disciplines. Future studies within the blended learning in STEM context could further develop and articulate these principles, determine when and where they are appropriate and further evaluate their impact.

Acknowledgements The Griffith Sciences Blended Learning team would like to acknowledge all of the exceptional learning and teaching staff who participated in the Griffith Sciences Blended Learning Model in 2017 and 2018 including all of the authors in this book. Their dedication and hard work have resulted in some excellent learning and teaching practices embedded across STEM disciplines.

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