[Australian Journal of Teacher Education](https://ro.ecu.edu.au/ajte)

Volume 47 | Issue 9 Article 5

2022

Developing Mathematics and Science Teachers' Ability to Design for Active Learning: A Design-based Research Study

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Abstract: This paper describes an approach to working with secondary preservice mathematics and science (M&S) teachers to develop their ability to design for active learning. It presents the design of a studio-style intervention that augments existing teacher education. It describes the way that these studios can be organised, with specific suggestions that a specialised learning designer, a subject matter expert, and administrative support be included to aid in the design for learning—on the justification that this can both improve the learning design as well as advance teacher learning. It describes a study in which 10 secondary M&S preservice teachers experienced this style of studio, through iterations of learning design sessions and teaching practice. The studio differs from existing models (such as the 'clinical model') through its focus on learning design, the structure of the learning network, and the way that it augments (rather than replaces) existing teacher education. The paper presents results from the study in terms of teacher self-efficacy and self-reported perceptions. It discusses a set of design principles that emerged through the process of developing and testing this model and proposes considerations for researchers or teacher educators looking to use a similar approach in future by focusing on the roles, tasks, and activities for members within the network.

Introduction

The past decade in Australia has seen impetus from government to change the way science, technology, engineering, and mathematics (STEM) subjects are taught within Australian schools, and to encourage teachers to use pedagogies that support active learning within these subjects (Marginson et al., 2013; Office of the Chief Scientist, 2012, 2016). This focus on active learning pedagogies is based on research that has identified related problems of: (a) declining numbers of students choosing to study STEM subjects in senior years of secondary school; (b) increasing need for STEM graduates in the workforce (Australian Industry Group, 2015; Consult Australia, 2019; Kennedy et al., 2014; Lyons & Quinn, 2010); and (c) significant evidence in the literature that active learning can lead to increased student engagement, retention, and performance (Akınoğlu & Tandoğan, 2007; Freeman et al., 2014; Prince, 2004).

Teachers benefit from having the capability to design for active learning, which is student-focused "learning by doing" rather than "instructor-focused 'teaching by telling'" (Freeman et al., 2014, p. 8410) and can encompass many pedagogical approaches (e.g., problem-based learning, project-based learning, inquiry-based learning, etc.). Active learning has been shown, across a range of studies, to improve student engagement and learning outcomes in M&S when compared to passive learning (Freeman et al., 2014; Prince, 2004). However, the way in which M&S are presently taught in Australia suggest that many teachers complete their initial teacher education (ITE) without the self-efficacy required for designing, developing, and teaching in a way that fosters active learning (Menon & Sadler, 2018).

This paper describes an intervention for preservice teachers (focused on M&S teachers) that augments ITE to help develop their ability to design for active learning. It takes a design-based research (DBR) approach (Barab & Squire, 2004; Collins, 1992) by iterating upon existing models and theory. In keeping with DBR, it makes a contribution by: (a) describing the model used as an improvement on prior models; (b) presenting results that support the use of the model in the form of teacher self-efficacy and self-reports; (c) articulating transferable design principles that became apparent through the research; and (d) placing the study in the context of theory about M&S teacher education. The approach that it describes is referred to as the Queensland University of Technology (QUT) Active Learning Studio (QALS) which is one of several research initiatives funded by the Office of the Chief Scientist of Australia to improve the education of STEM teachers (others are described by Anderson & Tully, 2020; Dawes et al., 2017; Timms et al., 2018).

Background

Studio interventions to augment ITE

ITE programs have a number of constraints (Mayer et al., 2015). They are typically accredited by external organisations (e.g., teaching boards or jurisdictions) to ensure course content will prepare teachers adequately for the profession. ITE programs have limited time available in which to cover this course content (including practical placements). The programs are also required to perform a role of gatekeeping through assessment to ensure that teachers who graduate are prepared to teach. ITE is often of high quality, but these limitations mean there will always be opportunities to improve how teachers learn (Mayer et al., 2015). The present study is conceived as an exploration of an approach to augment (rather than change) existing forms of ITE.

Two common sources of support for preservice teachers as they prepare for a teaching career are teacher educators associated with ITE (Lunenberg et al., 2007; Zeichner, 2005) and co-operating or inservice supervising teachers (Clarke et al., 2014). Where these are the only two types of support agent—with teacher educators encountered in the academy, and inservice teachers in the school—there can be a perpetuation of what Le Cornu and Ewing (2008) describe as the theory-practice dichotomy. This can lead to an artificial divide between educational theory, which is learned at university, and teaching practice, which is experienced in schools during practicum placements. This separation is often reinforced because of the lack of time available to inservice supervising teachers to spend with their preservice teacher charges to help them develop.

Preservice teachers can benefit from additional opportunities to put into practice and experiment with the ideas and pedagogies that they are learning (Darling-Hammond, 2010; Zeichner, 2010). Preservice teachers may also benefit from access to additional specialist support to assist with active lesson design, technical topic authenticity and contextuality, and resource sourcing and development.

The term studio model is widely used to describe practice-based and theory-informed opportunities for teacher learning (Margolis & Doring, 2012; Mor & Mogilevsky, 2013). Here we suggest a studio model for ITE that stays true to this definition with an additional recognition that they occur within the duration of ITE yet are, crucially, not a part of formal ITE (i.e., are optional practice-based opportunities).

Theoretical Foundations

Studio Models as Third Spaces and Learning Networks

Studio models aim to create a safe and trusted space that is a hybrid of the academy and the classroom, as implemented in the Hofstra example described below. This is a third space, where preservice teachers can try out various approaches and methods of teaching, safely take risks and potentially fail, and then reflect and receive feedback as they develop their skills (Zeichner, 2010). A key feature of third spaces is that they break down the hierarchy between professional practice and academic theory. While the Hofstra Studio was physically situated on a university campus, it was able to make a third space by bringing students to the campus and fostering a 'low-stakes' culture of development through exploration.

Studio models also convene a group of people who are invested in the development of the preservice teachers. In this respect a studio model is a design for a learning network which can be understood in terms of its set design (environments and tools), social design (roles and relationships), epistemic design (activities and resources for knowledge development), and design for co-configuration (ways that participants in a learning network can adapt it as needed) (Goodyear & Carvalho, 2014).

Studio models, as learning networks, aim to develop teachers' ability to design for and use active learning (Mor & Mogilevsky, 2013). This links to literature about the positive sustained effect active learning can have on student engagement, attitudes, interest and performance (Armbruster et al., 2009; Hyun et al., 2017; Prince, 2004) and where active learning is well-recognised to increase student performance in M&S subjects (Freeman et al., 2014; Theobald et al., 2020).

Self-efficacy and Design for Active Learning

The ability to teach using an active learning pedagogy is contingent upon teachers having both the capability and the self-efficacy—the confidence in their own competence—to do this kind of design for active learning. Teacher self-efficacy has been recognised as an important variable in determining a teacher's ability and motivation for using innovative classroom practices, including active learning, for improving student learning (Shaukat & Iqbal, 2012; Stein & Wang, 1988). A limitation on the use of active learning in M&S is that teachers need to have the self-efficacy (Bandura et al., 1999; Skaalvik & Skaalvik, 2007) to be able to design, develop, and teach in a way that fosters active learning.

It is anticipated that improvements in teacher self-efficacy could be used as an way of understanding preservice teachers' growth in terms of proficiency to design for active learning although this has not been tested.

Social Design of Preservice Teacher Studios

There are theoretical bases to suggest that in addition to an inservice supervising teacher, preservice teachers should benefit from also having within their learning network: (1) a specialist learning designer; (2) a content expert; and (3) administrative support.

Learning designers are specialists in overcoming the dichotomy between curriculum development and pedagogical implementation (Kickbusch et al., 2020). Learning designers differ from teacher educators (although they may also be teacher educators) in that their expertise is in facilitating co-design for learning (Goodyear & Dimitriadis, 2013; Kickbusch & Kelly, 2021; Lee, 2008). By working with a learning designer, preservice teachers get to experience the process of designing for active learning (i.e., they learn how learning designers work through participation in the co-design of what students will learn in the classroom) as well as receiving explicit coaching in how to grow as a teacher (Kickbusch et al., 2020).

Content experts are practicing industry professionals and/or university researchers with expertise in a subject area. Involving content experts in a preservice teachers' learning network is theorised to lead to the development of more authentic learning experiences for students (Morris et al., 2021). Authentic science refers to the way science is practiced. Preservice teachers can develop knowledge of authentic science through exposure to content experts (Lang et al., 2018; Lowrie et al., 2017). STEM content experts also act as role models and mentors in support of assignment design and specific learning activities (Gamse et al., 2017).

Finally, it seems likely that preservice teachers would benefit from administrative and logistical support for their experiments with pedagogy in a studio. A contributing factor to teacher stress and burnout is pressure caused by high workload pressures (Klassen, 2010; Sass et al., 2011). These pressures can result in teachers resorting to a one-dimensional, didactic style of teaching where students have little control of their own learning and lack opportunities to apply or elaborate on the knowledge presented (Niemi, 2002). Support from an administrative assistant who can aid teachers with gathering resources and organising logistics for teaching seems likely to assist with this.

Summary

The present study addresses the need to support Australian preservice M&S teachers to develop their ability to design for active learning. A studio model has been proposed to augment ITE involving convening a learning network as a third space for teachers. There is a theoretical basis for believing that including learning designers, content experts, and administrative assistants in a learning network for preservice M&S teachers (in addition to the usual inclusion of inservice supervising teachers) will be beneficial for the teachers involved.

In this context, a DBR study was conducted through 10 implementations of the QALS model. This paper describes the design of a learning network (in terms of set design, social design, epistemic design, and design for co-configuration) to support preservice M&S teachers by addressing the following questions:

1) What preliminary evidence is there to study the effectiveness of this design for a learning network for preservice M&S teachers?
2) What are the design principles used in developing the QALS that may generalise to similar projects?
3) How can the learning network be described so it might be implemented by other researchers or teacher educators?

These research questions were explored though a DBR study. DBR is an appropriate approach given the many uncontrollable variables involved in developing a new approach to augmenting preservice M&S teacher education. Accordingly, this research does not make claims about the efficacy of the approach being generalisable.

Methods

This paper reports on 10 different implementations of the QUT Active Learning Studio (QALS) conducted at four schools in Brisbane, Australia. There were minor differences between these implementations (described below). Each implementation lasted approximately four to six weeks. This phase of the study (10 implementations of the studio) was carried out over the course of three school terms (six months) and the research received approval from the university and school ethics review boards. Each implementation of the QALS involved one or two preservice teachers, a learning designer, an inservice teacher, a M&S expert, an administrative assistant, and a class of students at a school.

Design Foundations: The Hofstra Studio Model

The QALS model's design is inspired by the STEM Studio conducted at Hofstra University in New York (Plonczak et al., 2014). The Hofstra studio was developed in response to the problem that "preservice teachers were not transferring pedagogical understandings and practices learned in university methods classes to their practice" (p. 52) at a primary school level.

The Hofstra team responded to this issue by creating a "teaching and learning lab" (p. 52) that brought students and preservice teachers together on a university campus. The Hofstra studio was structured around three principles of: (1) using active learning and authentic assessment (e.g., through problem-based learning tasks as a platform for learning); (2) focusing upon designing learning tasks to be inclusive for all students (e.g., through universal design for learning); and (3) having a learning community for the preservice teachers that included teachers at multiple career stages. Key questions that were addressed in considering preservice teachers were: "How do we build a safe environment for preservice teachers to explore gaps in their content knowledge?" (p. 56) and "How might we help preservice teachers to recognize more fully the pedagogical moves we make to challenge and support learning?" (p. 56).

The Hofstra model emphasises the importance of preservice teachers being able to reflect upon their practice, and of having a safe and trusted space within which to do this (Plonczak et al., 2014). It is useful in the present study as a prior example of a studio-style program/intervention to augment teacher education.

Participants

Preservice Teachers

The QALS study involved 14 preservice secondary teachers; however, only 10 of these provided consent for their data to be used in the project (n=10). Preservice teacher participants were recruited through promotional activities that were scheduled during the orientation week of their education program. Participation in the project was on a voluntary (opt-in) basis; participation was not assessed and carried no credit towards the participants' formal education studies—this was important for participants to feel safe to take risks within the studio. All preservice teachers were enrolled in a one year, on-campus graduate education program at a university in Australia and had completed a prior tertiary undergraduate qualification in a scientific discipline or mathematics. The education program contained coursework in curriculum studies and pedagogical practices specific to each participant's teaching discipline.

Schools

Each QALS implementation involved collaboration with a school. In contrast to the Hofstra Studio model (where the studio occurred on a university campus) this project explored the possibility of creating the third space within a school setting. Each implementation involved one of four secondary schools, which were selected from the project team members' established professional networks. The schools were a mix of privately-owned and government-run schools, with enrolments ranging between approximately 1000 and 1500 students, as shown in Table 1. All schools were co-educational except Holy Spirit College which was a Catholic college for girls only.

The classes of school students were all from lower secondary school (years 7 to 10 in Australia, often referred to as "middle school"), where the students were aged between 11 and 14 years old. All classes had between 20 and 28 students.

School*	***Public / Private***	***Years***	***Gender***	***Approx. enrol.***	***Religion***
Grandview Secondary	Public	7-10	co-ed	1000	non-denom.
Holy Spirit College	Private	P-12	girls	1500	Catholic
Evergreen High	Public	7-12	co-ed	1250	non-denom.
Faith Academy	Private	7-12	co-ed	1200	Catholic

Table 1: Characteristics of schools involved in the study

Note. *School names have been changed for de-identification purposes.

Instruments and Analysis

The effect of the DBR intervention was measured using a pre- and post-test of teacher self-efficacy, the instrument developed and validated by Skaalvik and Skaalvik (2007) as a multi-dimensional measure based on the tasks they identified as central to the role of teachers in Norwegian schools (the questions that are included in this instrument are reported in full as part of the Findings section). Although other scales for self-efficacy have been used internationally (e.g., Friedman & Kass, 2002; Gibson & Dembo, 1984; Tschannen-Moran & Hoy, 2001, 2007), the Skaalvik and Skaalvik scale was used based upon its international adoption and its inclusion of factors for which the teacher is primarily responsible (instruction, adapting instruction, discipline, and motivation) as well as those that are more heavily affected by external factors outside the classroom (enforced cooperation or collaboration and system change). Due to the small sample size, analysis is limited to provision of descriptive statistics.

The self-efficacy survey responses were supplemented with the question *Please indicate how the QUT Active Learning Studio has helped you become a better teacher*, where the participants were invited to provide additional information of a qualitative nature about their experience within the project. These responses were analysed deductively as a means of reinforcing the test data results (see Yin, 2010) and to provide more detail about their changes in self-efficacy.

Finally, preservice teacher participants were interviewed via telephone within two weeks of concluding their experience. Interviews were semi-structured and focused upon their experience in terms of their teacher self-efficacy, experience in collaborating with members of the learning network, what they had learned by participating, and comparisons with their concurrent formal teacher education program. Typically, each interview ran for 10-15 minutes. This short duration of interview limited the possibility for depth of discussion in responding to questions. Transcripts of these interviews were analysed for unprovoked responses about their self-efficacy as a teacher to further understand changes and their perceptions of the learning network.

The Learning Network

The QALS provided an opportunity for preservice teachers to gain additional experience in designing, developing, and delivering extended (more than one lesson), contemporary and transdisciplinary learning experiences to students (within their normal school program). A central premise of the project was to provide concentrated support and specialised knowledge to support the preservice teacher in providing students with learning opportunities that are aligned with how science and mathematics are practised in the world.

For the QALS project, the preservice teachers' learning network is shown in Figure 1. Relationships were one-to-one or in groups (including initial sessions and classrooms). The introduction and overview brought together preservice teachers, the inservice teacher, the learning designer, and the M&S expert. Everybody was introduced to one another and the inservice teacher provided background information about the class that the preservice teacher was to teach, with reference to the topic and basic school logistics. The classroom involved the preservice teacher, inservice teacher, and students coming together in a school classroom (in place of the students' regular classes for that subject).

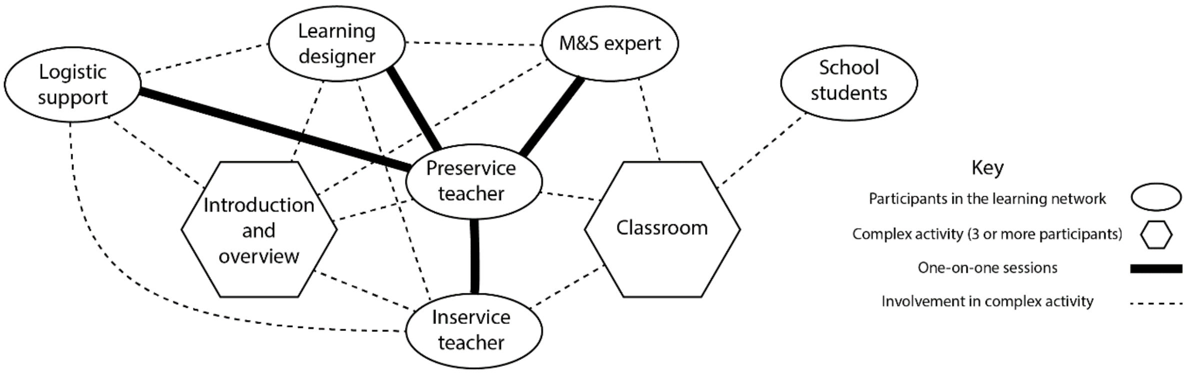

Figure 1: The social design of the learning network for each studio involving one-to-one relationships and complex activities involving three or more participants

Learning Designer

The learning designer (LD) had seven years of experience in learning design practice with prior experience as a teacher in secondary education (2 years) and tertiary and non-tertiary adult education (8 years). Within tertiary education, the learning designer had previous experience working with educators within numerous disciplines including science, mathematics, and engineering. The preservice teachers collaborated with the learning designer prior to each lesson (usually weekly) in a face-to-face design session (usually 2 hours) to design the overarching structure, activities, and intricacies of each lesson. These sessions also allowed the opportunity to reflect critically on the prior lesson as a means of improving the preservice teachers' own classroom skills and framing the subsequent lessons. Additional work has analysed these design sessions and describes how they were facilitated by the learning designer (Kickbusch & Kelly, 2021).

Content Experts

The M&S experts were either completing a PhD or were post-PhD in a field relevant to the lessons being taught (e.g., Astrophysics, Biomedical Science, Structural and Water Engineering, Robotics). They were recruited through the research team's network. The M&S experts collaborated with the preservice teachers via email, phone, and face-to-face.

The content experts contributed to the design and development of each unit of work (usually 4 weeks) by ensuring that the technical/scientific content was accurate. They suggested ideas and ways of demonstrating concepts and incorporating real-world examples to improve student understanding. However, where necessary these suggestions were tempered by the learning designer and the inservice teachers to ensure that they were aligned with the school curriculum.

Administrative and Logistical Assistant

The administrative/logistical support assistant was a professional staff member of the university hired to fulfil this role. As a part of their role, they provided extensive support to the preservice teachers to allow them to focus more heavily on designing and delivering their lessons. Some of this assistance included scheduling the introduction and overview session for each implementation, ensuring the preservice teachers understood school policies and requirements, sourcing specialist equipment, and negotiating teaching schedules for preservice teachers where there were clashes with their regular university program.

Inservice Teacher

Inservice teachers had a range of experience and were recruited through existing school relationships. As the teacher ultimately responsible for the class of students both before and after the project intervention, the inservice teacher assisted by determining the subject area being studied and providing background information about the class and students. Additionally, they were present in all lessons as state legislation required unregistered teachers (the preservice teacher participants) be supervised in class by an experienced, accredited, and registered teacher.

It is widely recognised that inservice supervising teachers are an important contributor to preservice teacher preparation and development (Clarke et al., 2014). However, within the QALS project, preservice teachers relied more heavily on support and guidance from participants within their learning network, particularly the learning designer and M&S experts.

Location and Timing of Meetings

Most meetings between participating preservice teachers and the members of the learning network happened on campus at the university running the project, except the introduction and overview meeting which was at the school involved in each implementation. The timing of QALS activities involved significant flexibility to fit in with the needs of each school. The project team adapted their schedule to fit with school timetabling and term structures, curriculum demands, inservice teacher availability, the age/year level of the school students and the subject topic under investigation.

Variations Between Preservice Teacher Experiences

All the preservice teachers worked with members of the learning network to design, develop, and deliver four lessons to their allocated class as outlined in Figure 1. However, whether the lessons taught by the preservice teachers were consecutive or interspersed between other lessons of the same school subject taken by the regular class teacher also varied to suit the needs of each school. Additionally, the preservice teachers' availability had to be considered because of the other demands of their teacher education program.

Topics Taught By Preservice Teachers

The topics under investigation and the specific year level of the students in each implementation is reported in Table 2. The content topic for each implementation was determined in consultation with the school leaders and the responsible inservice teachers for each respective class of school students to align with existing school programs. We note in studio QALS01 that PST01 and PST02 taught in tandem. This arrangement was made to alleviate the school's concerns about having to find a substitute teacher at short notice if a preservice teacher was sick and unable to teach.

Case ID	Preservice teacher ID	School	Year level	Topic
QALS01	PST01 PST02*	Evergreen High	9	Biofuels
QALS 02	PST05	Evergreen High	9	Biofuels
QALS 03	PST04	Faith Academy	10	Bridges
QALS 04	PST06	Faith Academy	10	Bridges
QALS 05	PST03	Grandview Secondary	7	Water security
QALS 06	PST07	Grandview Secondary	7	Water security
QALS 07	PST02*	Grandview Secondary	7	Water security
QALS 08	PST08	Holy Spirit College	7	Physics; Optics
QALS 09	PST09	Holy Spirit College	7	Physics; Optics
QALS 10	PST10	Holy Spirit College	7	Astrophysics

Table 2: Details of the 10 implementations of the QALS

Note. * PST02 participated in the QALS twice.

Examples of the types of active learning activities designed for these topics included; (1) students learning about forces on bridges by building and testing scale models of bridges, and (b) students examining the energy potential of different biofuel sources by determining, creating, and testing different biofuels.

Findings

Following, we describe changes in the preservice teachers' self-efficacy scores as one indicator of the effect of the implementation of the QALS. Recognising the small sample size, these changes in self-efficacy are provided as descriptive statistics only. We supplement these quantitative measures with certain qualitative findings from interviews that further indicate the efficacy of the QALS and the preservice teachers' experience within the project. These qualitative findings are specific to the instrument used but by extension might relate to teachers' self-efficacy to design for active learning.

We recognise the main contributions of the work are in the description of the network, the context for its implementation, and the explication of transferable design principles that we expect to be transferable to other contexts, rather than the establishment of a model of this specific implementation to be replicated in other contexts (Anderson & Shattuck, 2012; Barab & Squire, 2004).

Changes in Preservice Teacher Self-Efficacy (Pre/Post-Test)

Table 3 shows the average changes in self-efficacy rating across the whole project. It compares the preservice teachers' average self-efficacy rating prior to their participation in the project with their average rating following the intervention. The results show a net gain across all first-order dimensions and second-order factors within these dimensions. Additionally, Figure 2 is provided as a radar chart visualisation showing the average change in self-efficacy across all first-order dimensions measured and provides another representation that clearly shows increases in all dimensions measured.

The largest average increases in the first-order dimensions are seen in *Maintain discipline* and *Motivate students* which showed an average increase of +1.2 and +1.0. The smallest average increase in a first-order dimensions was seen in *Co-operate with colleagues and parents* which showed an average increase of +0.7 although this result still represents an overall increase.

Despite having one of the highest average increases, there is a notable difference within the *Motivate students* dimension. The second-order factor *Get all students in class to work hard with their schoolwork* showed one of the largest increases across all the second-order factors at +1.2. Within this same dimension, the second-order factor *Motivate students who show low interest in schoolwork* showed one of the smallest increases across all the second-order factors at +0.7. Furthermore, we see a large increase in the second-order factor associated with *Get all students in class to work hard with their schoolwork*. Here the pre-test average was 3.8, which falls on the negative uncertain end of the scale, and crossed into the positive certain end of the scale increasing to 5.0 following the intervention.

There is a further notable finding relating to the second-order pre-test averages within the dimension of *Maintaining discipline*. All four average lower-order ratings fall below 4 on the negative uncertain end of the scale prior to the intervention and cross to the positive certain end with ratings above 4 following the intervention.

There was only one other average change in a lower-order factor that crossed from the negative uncertain end of the scale into the positive certain end following the intervention. This was for *Adapt instruction to the needs of low-ability students while you also attend to the needs of other students in class* within the dimension of *Adapt instruction to student need* which moved from 3.6 to 4.6 following the intervention.

The smallest average increases in the second-order factors are seen in *Find adequate solutions to conflicts of interest with other teachers* +0.4 and *Co-operate well with most parents* +0.5 (both within dimension *Co-operate with colleagues and parents*) and *Teach well even if you are told to use instructional methods that would not be your choice* +0.5 (within dimension *Cope with change*). These average changes are still increases but are highlighted because they were the smallest of the increases shown across every measured second-order factor.

ID	**Self-Efficacy Measure** *"How certain are you that you can:"*	Pre-test avg.	Post-test avg.	avg. change
1	**Instruction (combined)**	**4.6**	**5.4**	**+0.8**
1.1	Explain central themes in your subjects so that even the low-achieving students understand.	4.5	5.3	0.8
1.2	Provide good guidance and instruction to all students regardless of their level of ability.	4.4	5.5	1.1
1.3	Answer students' questions so that they understand difficult problems.	4.4	5.2	0.8
1.4	Explain subject matter so that most students understand the basic principles.	4.9	5.6	0.7
2	**Adapt instruction to student need (combined)**	**4.0**	**4.8**	**+0.8**
2.1	Organise schoolwork to adapt instruction and assignments to individual needs.	4.1	4.7	0.6
2.2	Provide realistic challenge for all students even in mixed ability classes.	4.2	5.0	0.8
2.3	Adapt instruction to the needs of low-ability students while you also attend to the needs of other students in class.	3.6	4.6	1.0
2.4	Organise classroom work so that both low- and high-ability students work with tasks that are adapted to their abilities.	4.0	4.8	0.8
3	**Motivate students (combined)**	**4.1**	**5.1**	**+1.0**
3.1	Get all students in class to work hard with their schoolwork.	3.8	5.0	1.2
3.2	Wake the desire to learn even among the lowest-achieving students.	4.2	5.2	1.0
3.3	Get students to do their best even when working with difficult problems.	4.2	5.2	1.0
3.4	Motivate students who show low interest in schoolwork.	4.2	4.9	0.7
4	**Maintain discipline (combined)**	**3.4**	**4.6**	**+1.2**
4.1	Maintain discipline in any school class or group of students.	3.6	4.8	1.2
4.2	Control even the most aggressive students.	2.6	4.2	1.6
4.3	Get students with behavioural problems to follow classroom rules.	3.5	4.5	1.0
4.4	Get all students to behave politely and respect the teachers.	3.7	5.0	1.3
5	**Co-operate with colleagues and parents (combined)**	**5.1**	**5.8**	**+0.7**
5.1	Co-operate well with most parents.	5.2	5.7	0.5
5.2	Find adequate solutions to conflicts of interest with other teachers.	5.3	5.7	0.4
5.3	Collaborate constructively with parents of students with behavioural problems.	4.5	5.5	1.0
5.4	Co-operate effectively and constructively with other teachers, for example, in teaching teams.	5.5	6.3	0.8
6	**Cope with change (combined)**	**4.7**	**5.5**	**+0.8**
6.1	Successfully use any instructional method that the school decides to use.	4.9	5.7	0.8
6.2	Manage instruction regardless of how it is organized (group composition, mixed age groups, etc.).	4.5	5.5	1.0
6.3	Manage instruction even if the curriculum is changed.	4.6	5.4	0.8
6.4	Teach well even if you are told to use instructional methods that would not be your choice.	4.8	5.3	0.5

Table 3: Average changes in preservice teacher self-efficacy across all dimensions

Note. Results shown as full program average. Adapted from the Norwegian Teacher Self-Efficacy Scale (Skaalvik & Skaalvik, 2007).

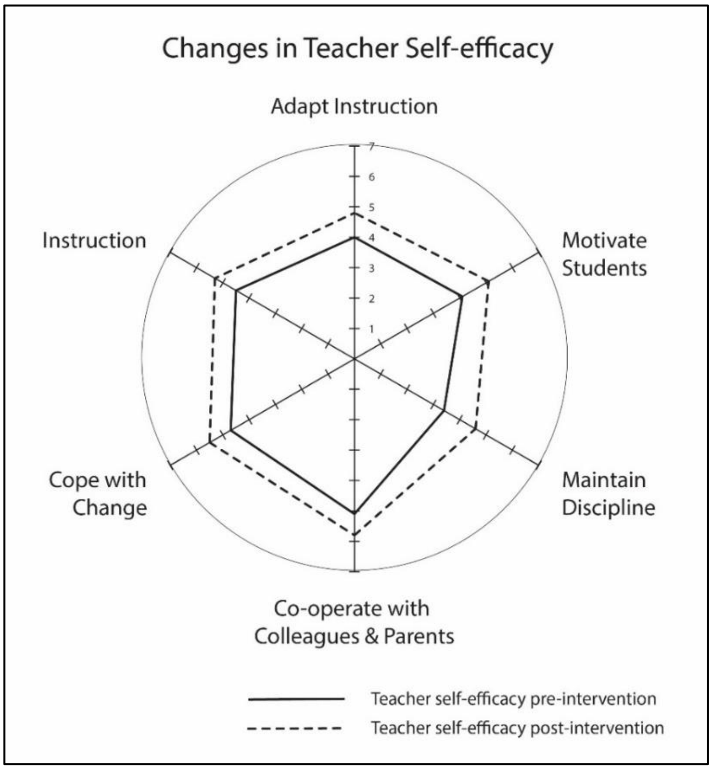

Figure 2: Average change in preservice teacher self-efficacy all cases.

Note. Adapted from the Norwegian Teacher Self-Efficacy Scale (Skaalvik & Skaalvik, 2007).

Qualitative Evidence for Efficacy of the QALS

The results from pre- and post-tests indicated that, for the 10 teachers studied, there were improvements in self-efficacy across all areas. However, these findings are limited by the small sample size and lack of controls. As such, they should not be generalised beyond the specific circumstances of this study. However, they do provide some evidence that—in the implementations described—it is likely that the QALS had a positive impact upon teachers' self-efficacy in the six dimensions measured. It is further reasonable to suggest the three self-efficacy dimensions of Instruction, Adapt instruction, and Motivate students might relate to teachers' self-efficacy to design for active learning.

These results can be further strengthened by the following inclusion of self-reported quotes from preservice teachers' surveys/interviews. These quotes were selected for inclusion only where no quotes with an opposing view were found anywhere within the study.

Firstly, the literature suggests there is a direct correlation between highly motivated school students and a lower incidence of classroom disciplinary issues and vice versa (Arens et al., 2015). This is likely to be reflected in links between the two self-efficacy dimensions *Maintain discipline* and *Motivate students.* A comment by PST04 supports this view. PST04 said, "putting together lessons that are themselves interesting helps motivate students" (interview). Active learning is a key factor for motivating students (Armbruster et al., 2009; Freeman et al., 2014; Prince, 2004) and, by extrapolation, helps minimise classroom disciplinary issues. This sentiment is supported by PST01 who says, "I have become more confident in the [active learning] teaching strategies I use, and the students have responded positively to this" (survey).

Further, the dimensions of *Instruction* and *Adapt instruction* (to student need) are again likely to be related. It is possible that these dimensions improved somewhat because of the student-centred and empathetic focus of the extensive sessions between the preservice teachers and the learning designer. Qualitative feedback from preservice teachers support the self-efficacy data:

> *"Knowing the content is one thing but being able to communicate it effectively to students … I realised that, wow, I can do this. This is great!" (PST01, interview).*
>
> *"I have shifted my focus from, 'I need to teach this' to, 'Do the students understand what I'm teaching?' I feel more comfortable extending activities and discussion, if it benefits the students, and less worried about getting through all the content in one lesson." (PST02, survey).*

One consideration in interpreting findings is that it is possible that the improvements in teacher self-efficacy could have been due to providing the preservice teachers with additional opportunities to practice teaching (outside of the opportunities afforded through their ITE program). If this were the case, the actual design of the learning network would not be as significant as hypothesised. Our quantitative results do not allow this to be ruled out, though it seems unlikely. The idea that self-efficacy is due to the network's design network is echoed in further feedback from the preservice teachers:

> *"I loved having the sessions with [the learning designer]. It just gave me so many excellent ideas for how to tap into things that kids are interested in, and how to make the lessons engaging … [my] confidence has improved." (PST06, interview).*
>
> *"Collaborating with [the] inservice teacher, engineer and learning designer to help with ideas for engaging activities has helped me become a better teacher" (PST06, survey).*

Discussion

The QALS Model as a Learning Network

The study is based upon an understanding that this kind of studio approach augments traditional ITE as a third space where preservice teachers can engage with a learning designer and a content expert. It is a context where risk-taking is encouraged, where there is little (or no) consequence for failure, and where there is a well-designed learning network of support for the preservice teacher. The findings from this study are useful to others seeking to develop interventions for M&S teachers that improve their ability to design for active learning. In the QALS there was a focus upon using DBR to establish a type of learning network that could support teachers in doing this, which will be described through the framework articulated by Goodyear and Carvalho (2014) through its set design, social design, epistemic design, and design for co-configuration.

The set design of this model concerns the 'stage' upon which the interactions between the preservice M&S teacher and the other members of the learning network occurred and includes physical spaces as well as the tools they used to communicate. Interactions between the preservice teachers and other members of their learning network (Figure 1) were either conducted face-to-face on the university campus (as a mutually convenient location) or via phone or email (typically for quick or goal-directed conversations rather than lengthy discussions).

The social design for the QALS builds upon the traditional model in which a preservice teacher gains experience under the supervision of an inservice teacher while being responsible for a class of students. It adds a specialist learning designer, a content expert, and an administrative support person (Figure 1) and these relationships involved particular roles and patterns of interaction.

Interactions between the preservice teachers and the learning designer entailed complex, lengthy, and regular interactions (at least weekly and approximately two hours in length each time) as they worked closely in a process of co-design for learning. Interactions between the preservice teachers and the M&S content experts were less frequent but also complex to ensure the contemporary authenticity of the designed scientific activities. The interactions between the preservice teachers and the inservice teachers and administrative support person were typically short and focused on the practicality of the design for a school setting and provision of administrative and logistical support. Roles of participants were clear, as described above in The Learning Network.

From the perspective of epistemic design (design of the activities and tasks), it is the activity between the preservice teachers and the project team that is of significance for description and analysis of the model. There is little value in detailing the frequency or duration of the design sessions and taught lessons more fully than has been described already. The preservice teachers worked with the learning designer intensively before every lesson, had access to the other learning network participants as required, and taught four distinct connected lessons.

Another unique feature of this program is the very high teacher/student ratio, where the preservice teacher is considered the student and the providers of support; i.e., the learning designer, content expert, logistics coordinator and inservice teacher, are considered the teacher/s. This level of concentrated support over an extended period of weeks is rare and costly, a limitation of the approach.

We appreciate the challenges of designing for co-configuration within new ways of working (described by Engeström, 2004) in that detailed interactions are both created and learned consecutively by the participants themselves. However, we acknowledge that more understanding is needed about *how* the sessions between the preservice teachers and the learning designer eventuated. This type of analysis would reveal details of how the co-design processes are realised when designing for student learning, and also reveal how preservice teachers can be coached to develop their capability to design for learning, improving their teacher self-efficacy (Kickbusch & Kelly, 2021).

Transferable Design Principles

Claims cannot be made about the generalisability of specific findings reported from the QALS model, given the small sample size and specific context of each intervention. However, there are design principles for the QALS model that have a theoretical basis and that we expect to be transferable to other contexts. Many of these design principles can be seen as confirming and further enriching the principles outlined by Plonczak et al. (2014).

First (epistemic design), it is recognised that designing for active learning is difficult; teachers need the ability to take risks and experiment to develop self-efficacy. Iterations of design for active learning with the support of experts, followed by teaching those classes with the support of a supervising teacher, followed by reflection and further design for learning, were observed in the present study to be an effective way of developing this self-efficacy. This is similar to findings in the Hofstra model and those found in a review of clinical models of teacher education (Burn & Mutton, 2015). The design of a studio differs to a clinical model in that, crucially, preservice teachers are not being assessed and can be encouraged to take risks that are truly free of consequences in terms of their otherwise formally assessed ITE program.

Second, (social design), there is a principle of having diverse forms of support within the learning network that have a non-hierarchical organisation. There are clear benefits to having a breadth of knowledge present within a learning network for preservice teachers (Wenger et al., 2011). Preservice teachers further benefit from feeling like equal participants in developing teaching knowledge and from having autonomy to initiate boundary-crossing, rather than feeling subject to authority (Zeichner, 2010). Diverse forms of support and absence of hierarchy were present within both QALS and the Hofstra model. A significant variation in the social designs of the two is that the QALS model brought together a range of specialists (learning designer, content expert, inservice teacher, administrative support), while the Hofstra model achieved diversity through a range of experienced teachers at different stages in their career. Further work is needed to know which is more effective, although it is reasonable to believe that specialists might bring extra benefits to a learning network. The inclusion of the learning designer and the preservice teachers' frequent contact with them was the key feature of the QALS model. It should also be noted that it takes additional resources (time, money) to bring such specialists into a learning network.

Third (epistemic design), the learning network needs to emphasise key features of design for active learning. In the QALS model the learning designer was a constant advocate for three principles (following Dohn et al., 2020): (1) establishing clear learning outcomes for the school students as a foundation for design activity; (2) giving preservice teachers ample time to fully design for learning to help ensure the best chance of successful classes; and (3) maintaining a consistent student-centred focus in developing all activities.

These principles are intended to guide the design process rather than form a set of rigid rules. It is important to reiterate the learning network of concern when describing the QALS model is that of the preservice teachers. However, it can also be noted there is another emergent learning network that is centred upon the school students. In effect, the QALS was a learning network for preservice teachers. That learning network then collaborated to design a learning network for the school students within each implementation of the QALS.

The QALS (as with the Hofstra model) was conceived of as a form of third space (Zeichner, 2010) for preservice teachers. The aim was to create a setting that helped these teachers to bridge the theory/practice dichotomy through an authentic, yet low-risk environment (i.e., no assessment items, non-hierarchical, outside of formal ITE). In reflecting upon the research, it is significant that the QALS was conceived of as augmentation to ITE. There are two sides to this issue. On one hand, it makes it easier to implement a studio when it is run as an 'opt-in' augmentation that sits outside of formal ITE (with its needs for accreditation). On the other hand, there are challenges in resourcing studios outside of formal ITE (e.g., who pays for it?) and there can be challenges in having teacher educators understand the value of having such an augmentation. A challenge for future implementations would be to balance these issues while staying true to the design principles of the QALS model.

The QALS is a learning network that the research team designed with an aim of developing M&S preservice teachers' ability to design using active learning pedagogies. Learning designers are not typically included in learning networks for preservice teachers (in ITE or otherwise). Even where a teacher educator might have the skills of a learning designer they often do not self-identify as such, and there is potential conflict between these dual roles. Similarly, content experts—who ensured the authenticity of the scientific practice that was designed—are not typically included in learning networks for preservice teachers. Again, although teacher educators are usually content experts there is potential conflict between responsibilities (i.e., where they also need to teach course material, conduct assessment, and mentor preservice teachers). There appears to be value in having specialists available to preservice teachers within their networks, with benefits from clarity in these roles that becomes visible when the network is considered through the lens of social design.

In this study, self-efficacy was used as an initial way of understanding preservice teachers' growth in terms of design for active learning. It is recognised that this is an imperfect instrument, in that the six self-efficacy dimensions (Skaalvik & Skaalvik, 2007) look at teachers' general self-efficacy. How might a more specific instrument for measuring teachers' self-efficacy to design for active learning be developed? Prior work has suggested that teachers require a design thinking mindshift (Kickbusch et al., 2020) to design for active learning. Further, the construct of teachers' creative self-efficacy (Cayirdag, 2017) may be relevant to such work.

One question addressed in this paper, but requiring further investigation, is whether there may be merit in integrating specialist learning designers or subject content experts (post-PhD) within formal ITE.

A future phase of the research would continue to improve the design described here through further phases of design and testing. This would involve, first, the makeup of the designed preservice teacher learning network and, second, the practicalities of a design-teach-reflect cycle for active learning pedagogies. It would also involve further experiments within additional and different educational contexts.

Conclusions

This paper has described the QALS model through a design-based research study. Studio models are characterised as augmenting ITE through provision of a third space that includes experienced teachers. The QALS model is further characterised by: (a) being explicitly conceived of as a model for convening preservice teacher learning networks; where (b) those networks include a specialist learning designer, content expert, and administrative support person, in addition to the inservice (supervising) teacher. The paper has suggested a configuration for the learning network, with specific roles and activities. It has emphasised the importance of the learning designers and the content experts and has hypothesised that the gains observed in teacher self-efficacy and in teacher self-reports may be due to their involvement within the learning network.

The QALS model is intentionally established as an augmentation to traditional ITE programs offering preservice teachers' additional theory-informed practical opportunities to experiment with active learning pedagogies. The study has suggested that the QALS model did help to develop preservice teacher self-efficacy and helped them to develop their ability to design for active learning. The study has led to the articulation of a set of transferable design principles for the design of studios for preservice teachers.

Funding Details

This work was supported by the Australian Government Department of Education and Training as a part of the Enhancing the Training of Mathematics and Science Teachers (ETMST) program.

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