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Developing teachers' interdisciplinary expertise

A scoping study

2024

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Overview¹

It is widely acknowledged that interdisciplinarity is vital to future economic prosperity, health, and social wellbeing (Barry & Born, 2013). Similarly, teachers face an increasing need to engage in teaching practices that extend beyond their disciplinary specialisation. They are called upon to teach cross-curricula topics, contributing to STEM (science, technology, engineering and mathematics) and STEAM (science, technology, engineering, arts and mathematics) education, and to engage in other integrative teaching and learning practices aimed at helping students to address transversal real-world challenges by developing the capabilities necessary to build upon firm disciplinary foundations and to integrate different areas of knowledge and ways of knowing.

Despite clear recognition of the urgent need to develop people's capabilities to work across disciplines (Cooke & Hilton, 2015), pre-service teacher education and in-service teacher professional development programs rarely focus on developing the expertise necessary to do this. In pre- and in-service teacher education, provision tends to be fragmented and programs informed by general theories and evidence from teacher professional development, with little reference to theory or evidence specific to interdisciplinary knowledge work, teaching or learning (Enderson et al., 2020; Evans, 2019; Luft et al., 2020).

The project

This report is a part of the project 'Developing teachers' interdisciplinary expertise', funded by a NSW Department of Education Strategic Leveraging grant and led by a research team from the University of Sydney and the University of Queensland.

The project aims to translate some findings from the research project 'Developing interdisciplinary expertise in universities', funded by the Australian Research Council, to NSW teacher education and professional development.

The [Developing Teachers' Interdisciplinary Expertise](#) project aims to extend our collective understanding of interdisciplinary expertise, and how to enhance its development for pre- and in-service teachers and, through that, how to strengthen students' capabilities for interdisciplinary work. Key objectives include:

1. To identify the principal challenges and barriers teachers face—and the capabilities and resources they need—when developing their students' abilities to engage in productive interdisciplinary project work.
2. To create a framework for developing teachers' interdisciplinary expertise, including a set of reusable design resources for integrating the development of interdisciplinary expertise in pre-service teacher education and in-service professional development.

¹ Based on Markauskaite et al. (2023a).

The scoping study

The first phase of the project involved a scoping study that aimed to identify current focus areas, practices, and challenges in developing pre-service and in-service teachers' interdisciplinary expertise. The initial work involved developing a consultation paper integrating insights from the project 'Developing interdisciplinary expertise in universities' and a scoping literature review on the development of teachers' interdisciplinary expertise (Markauskaite et al., 2023a). The follow-up work involved conducting one-hour consultation interviews, where invited participants with relevant expertise and experience shared their knowledge in response to the consultation questions (Markauskaite et al., 2023b).

This report

The main outcomes from the above work were originally presented in two separate documents (Markauskaite et al., 2023a, 2023b). This report does not report new findings but integrates these outcomes into a single document. It was produced with the aim of consolidating these research outcomes in a format more suitable for further reference and dissemination.

The first part of this report presents key insights from the desk study that led to the development of consultation questions. It is based on the earlier consultation paper (Markauskaite et al., 2023a). The second part presents the methodology and key results from the consultation interviews. It is based on the earlier consultation report (Markauskaite et al., 2023b).

The project overview is presented in Appendix 1.

Website: <https://interdisciplinaryexpertise.org/developing-teachers-interdisciplinary-expertise>

Terminology²

This paper uses the following definitions:

- **Discipline:** a body of knowledge or a branch of learning with particular characteristic features (concepts, theories, methods, objects, etc.). English Literature, History, Biology, and Physics are examples of disciplines. Disciplines are organised into broader disciplinary areas or disciplinary fields, such as Humanities and Science.
- **Interdisciplinarity:** all forms of engagement and collaboration across disciplines and with other non-academic knowledge fields and activity spheres (private, community, industry, etc.). Interdisciplinarity is used as an ‘umbrella’ term that includes different degrees of interaction across fields, from **cross-disciplinarity** (which involves exploration of the same topics from several perspectives without integrating them) to **trans-disciplinarity** (which involves integration and transcendence of existing knowledge fields and the emergence of new worldviews).
- **Expertise:** the capacity to perform productively, knowledgeably, and skilfully in relation to an encountered situation and context. Expertise includes the *relationship* between personal attributes (knowledge, skills, dispositions, etc.) and a broader activity system (shared goals, cultural, social, material and knowledge resources, other people, etc.).
- **Interdisciplinary expertise:** the capacity for productive, knowledgeable, and skilful engagement in those kinds of knowledge practices that involve several disciplines or other knowledge fields and the ability to foster connections between them.
- **Teachers’ expertise** and **teaching expertise:** these terms are used synonymously. They refer to the relationship between the teacher’s attributes and their teaching activity (activity that is situated within a larger system).
- **Competence, skills and capability:** common terms used in the literature to describe various capacities related to expertise. **Competence** often refers to the proven functional ability to appropriately use knowledge, skills, and other personal attributes (dispositions, values, etc.) in work or learning situations (Council of the European Union, 2017; OECD, 2019). **Skills** are sometimes described as a component of competence, but often ‘skills’ and ‘competencies’ are used as synonyms (e.g., 21st-century skills/competencies). **Capability** refers to “everything a person can think or do, given an appropriate context” (Eraut, 1998, p. 135). Capability is a broader term than competence. It refers to one’s potential and ability in relation to personal choices and contexts, not necessarily demonstrated/proven performance.

² Based on Markauskaite et al. (2023a).

Introduction³

The first part of the report presents initial ideas about teachers' expertise for interdisciplinary teaching. It is based on an initial analysis of key curriculum and policy documents, a scoping literature review, and the project team's research. It seeks to identify and map current practices and needs for developing in-service and pre-service teachers' interdisciplinary expertise in the Australian and, particularly, NSW school contexts.

It is structured around the following four questions:

1. What are the most important areas of teachers' interdisciplinary practices and needs for professional learning?
2. What kinds of expertise and resources do teachers need for productive interdisciplinary teaching?
3. What are the key features of effective professional education for interdisciplinary teaching?
4. What are the main barriers and enablers for developing pre- and in-service teachers' expertise for interdisciplinary teaching?

These questions, as well as ideas presented in this part of the report, were used to stimulate discussions during the consultation interviews presented in the second part of this report.

³ The first part of this report is based on Markauskaite et al. (2023a).

Question 1: What are the most important areas of teachers' interdisciplinary practices and needs for professional learning?

Research literature and policy documents show that teachers engage in a range of interdisciplinary practices that broadly relate to two intertwined aspects: 1) teaching, and 2) professional learning.

Interdisciplinary teaching, such as teaching integrative, interdisciplinary curricula and developing students' transversal capabilities, is at the centre of teachers' engagement with interdisciplinarity. Teachers and teaching are also surrounded by a broader set of interdisciplinary professional learning practices related to the interdisciplinary nature of foundational knowledge for teaching and the interdisciplinary nature of professional learning (see Figure 1 and the more detailed explanation below).

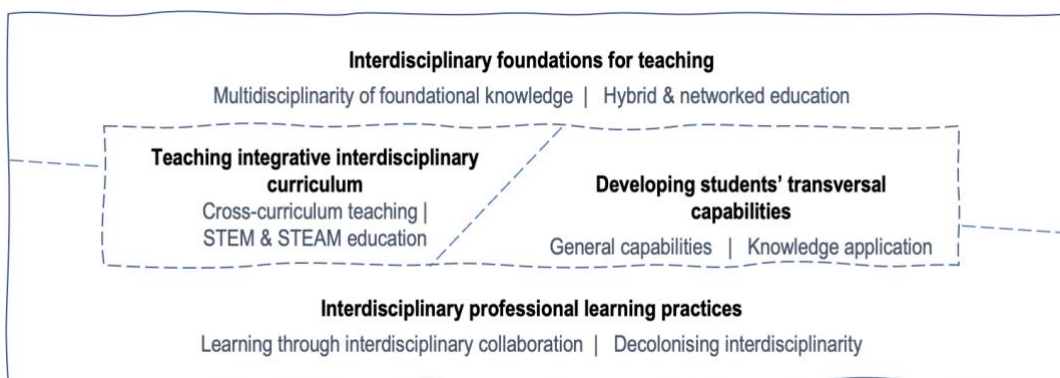


Figure 1: Main facets of teachers' interdisciplinary practices

Interdisciplinary foundations for teaching

Multidisciplinary of teachers' foundational knowledge. Education, as a professional field, draws on knowledge from multiple disciplines, such as psychology, neuroscience, sociology, philosophy, anthropology, and others. This interdisciplinarity is particularly salient in recent calls for teachers to draw upon multiple social disciplines when addressing issues of diversity, inequity, and social justice (Warren & Venzant Chambers, 2020) and to embrace the newest perspectives and evidence on how people learn from the interdisciplinary field of the learning sciences (Nasir et al., 2021). This is prominent in the NSW Curriculum Review (Masters, 2020), which asserts that findings from research into how humans learn, and the conditions that promote successful learning, which “has spanned a range of disciplines, including neuroscience, cognitive science, educational psychology, educational research and sociology” (p. 91), should be “routine features of initial teacher education programs and ongoing professional learning, as well as informing sequencing in the school curriculum” (p. 111).

Hybrid and networked education. The increasing uptake and fusion of digital technologies into many aspects of education, including pedagogical practices, learning environments and educational management, further ‘hybridises’ teachers’ expertise. Teachers are expected to master technological pedagogical content knowledge (TPACK) (Koehler & Mishra, 2009) and to be proficient in a number of disciplinary areas that are specifically related to information and communication technologies (e.g., cybersecurity, cyberbullying). They are also expected to enhance inclusivity by embracing universal design for learning

principles that draw on evidence from numerous disciplines (Howard, 2003). They need to make sense of the conflicting evidence, and understand the science, that underpins pedagogies and teaching in new physical and hybrid learning spaces (Woolner & Hall, 2010). They should be knowledgeable about data science, develop data literacy, and be skilful at using learning analytics systems (Mandinach & Gummer, 2016). Remote teaching during the COVID-19 pandemic raised further questions about the capabilities needed for this kind of teaching and highlighted the importance of networked learning and of weaving together knowledge from humanistic and other disciplines when addressing issues of wellbeing, care, justice, etc. (Hill et al., 2020; König et al., 2020; Mutton, 2020).

Teaching integrative, interdisciplinary curriculum

Cross-curriculum teaching and learning. Many important topics pertinent in today's society (e.g., sustainability, health, equity) can only be properly understood and addressed by engaging with perspectives from multiple disciplinary domains; they do not sit comfortably within any single subject. Moreover, integrative cross-curriculum teaching offers an opportunity to make the teaching profession more intellectually engaging (Mockler, 2018). The Australian National Curriculum includes three cross-curriculum priorities (Aboriginal and Torres Strait Islander histories and cultures; Asia and Australia's engagement with Asia; and Sustainability) that, while not requiring integration, should be taught across disciplinary learning areas. The Shape of the Australian Curriculum (Australian Curriculum, Assessment Reporting Authority [ACARA], 2020) paper recognises the need for teachers to be proficient in cross-curriculum teaching: "Teachers choose how best to introduce essential concepts and processes, and how to progressively deepen understanding of discipline-based content, including through *cross-disciplinary* learning that broadens and enriches each student's learning." (p. 15). The NSW Curriculum Review (Masters, 2020) recognises the importance of integrative teaching, but places greater emphasis on the vertical integration of "theory and practice" and "knowledge and skills" within the subjects than it does on horizontal integration across them (p. 113).

Science, technology, engineering and mathematics (STEM) education. STEM education is seen as essential for addressing decreasing student interest and achievements in STEM disciplines and a growing shortage of professionals in STEM-based industries and services. This coincides with a need to address a growing shortage of STEM teachers who can teach individual STEM subjects, teach across STEM subjects and teach beyond the boundaries of STEM subjects. "Increasing teacher capacity and STEM teaching quality" is a key area for national action in the Australian National STEM school education strategy 2016–2026 (Education Council, 2015). However, the implementation of this strategy itself relies on the teachers' interdisciplinary expertise. For example, there is an expectation that STEM teaching and learning will be intertwined with the "development of skills in cross-disciplinary, critical and creative thinking, problem solving and digital technologies" (p. 3) and that teachers will be capable of engaging in "effective partnerships with tertiary education providers, business and industry" (p. 6). Similar aims are echoed in STEM initiatives and programs implemented at the State level (NSW Government, 2022). Internationally, there are strong movements to expand STEM education to include the arts, humanities and social sciences, known as STEAM (science, technology, engineering, arts and mathematics) (Perignat & Katz-Buonincontro, 2019). However, this trend is less common in the current Australian and NSW educational contexts.

Development of students' transversal capabilities

General capabilities. Worldwide attention on the development of general student capabilities and 21st-century competencies has important implications for teacher preparation (Greenhill, 2010; Kereluik et al., 2013). The Australian National Curriculum includes seven general capabilities: Literacy, Numeracy, Information and communication technology capability, Critical and creative thinking, Personal and social capability, Ethical

understanding, and Intercultural understanding. The Shape of the Australian Curriculum (ACARA, 2020) paper acknowledges that these capabilities are interdisciplinary “...learning does not fit neatly into a curriculum solely organised by learning areas or subjects that reflect the disciplines. In a world where knowledge itself is constantly growing and evolving, students require a set of knowledge, skills, behaviours, competencies and dispositions—that is, *general capabilities*—that are developed within and can apply across learning areas.” (p. 13). Literature reviews point out that, to support students’ development of general capabilities, teachers first need to develop these capabilities and master relevant pedagogies themselves (Erstad & Voogt, 2018; Kereluik et al., 2013; Voogt & Roblin, 2012). Surprisingly, there are very few specific models or suggestions on these teachers’ capabilities should be developed in pre-service or in-service teacher education (Greenhill, 2010).

Knowledge application, vocational education and integrated learning. An important aim of learning is to develop students’ ability to transfer disciplinary knowledge learnt in different subjects and apply it to solving real-world problems. This requires teachers to embrace integrative teaching and learning practices that juxtapose theory and practice, combine guidance with hands-on experiences, and position disciplinary knowledge in relation to other perspectives and disciplines when solving real-world challenges (Markauskaite & Goodyear, 2017). The importance of students’ skills in applying theoretical knowledge, and the role of integrative learning, are widely acknowledged in the NSW educational context. For example, the NSW Curriculum Review (Masters, 2020) emphasises the importance of vocational subjects and claims that teaching needs to address two unproductive dichotomies between: 1) disciplinary knowledge and general capabilities, and 2) academic learning and vocational learning: “every subject should adopt an integrated approach to the development of knowledge, skills and attributes and, in the later years of school, should be designed to prepare students simultaneously for further study, life and work” (p. 79). This comes together with the expectation that teachers will use integrative pedagogies. The main focus, however, as mentioned previously, is ‘vertical’ integration within the subjects: “Within each subject, students should be given opportunities to explore meaningful applications of what they are learning” (p. 79).

Interdisciplinary professional learning practices

Learning through interdisciplinary collaboration. Engagement in professional development with colleagues from different disciplinary backgrounds is an important aspect of teachers’ professional learning. Also important are integrative, cross-curricular teaching activities, including teaching students from EALD backgrounds and addressing issues of diversity, equity and inclusivity. In the NSW and broader Australian context, co-creating lesson plans and co-teaching have been a common professional development approach in STEM and cross-curricular areas (ACARA, 2016). Such professional learning relates not only to the immediate outcome (i.e., the success of a lesson or a project), but also to what teachers learn about their own discipline, about other disciplines and about how to learn and work across these disciplinary and other knowledge boundaries (Grossman et al., 2001). This form of learning can also involve collaborations with experts and communities beyond traditional disciplines, such as mentoring by Aboriginal cultural educators (Burgess & Harwood, 2021) and teachers’ activism.

Decolonising interdisciplinarity—social, environmental, and epistemic justices. Teachers are increasingly called to engage with the voices and ways of knowing of those who have been underrepresented in Western academic knowledge. While interdisciplinarity is often seen as an opportunity to solve some of these issues, Western interdisciplinary science and pedagogies have frequently embodied similar injustice issues. For example, females, LGBTQ+, and First Nations Peoples are underrepresented in STEM (Buck et al., 2020; Murphy et al., 2019). Power and prestige hierarchies are common among mathematics,

science, technology and engineering disciplines and the teachers teaching them (Ellis & Williams, 2020; Quan et al., 2019). STEM orientation towards economic benefits and employability has marginalised humanistic and social rationales and disciplines (Takeuchi et al., 2020) and limited opportunities to engage in more socially and environmentally just, post-humanistic ways of thinking and pedagogies (Burnard et al., 2022). Educational literature points out the need to make explicit the epistemological assumptions that underlie current practices of interdisciplinarity and interdisciplinary education (Quan et al., 2019; Takeuchi et al., 2020). Professional education practices involving deeper epistemological interrogation into the nature of interdisciplinarity and issues of power and equity (such as teacher activism) are only emerging.

Discussion questions

The above perspectives show that teachers' interdisciplinary expertise is multifaceted. It cannot be developed in a single course or professional development program and is likely to involve multiple interweaved activities and pathways. It is therefore important to map different facets and identify the most critical aspects in a specific context and time, as follows:

1. What are the main areas of teachers' interdisciplinary practices in NSW schools?
2. What kinds of interdisciplinary practices are most critical in current and future teaching contexts in NSW schools? Why?
3. What kinds of interdisciplinary professional education do in-service and pre-service teachers need the most?

In the rest of this paper, we focus on expertise for interdisciplinary teaching.

Question 2: What kinds of expertise and resources do teachers need for productive interdisciplinary teaching?

The need to prepare teachers for interdisciplinary practices is acknowledged in various policy documents and in the research literature. However, surprisingly few models or frameworks attempt to articulate what constitutes teachers' expertise for these interdisciplinary practices or, specifically, for interdisciplinary teaching.

The majority of documents and literature reviews that do address this question focus on teachers' preparation for specific areas of cross-curricular or integrative teaching, such as the preparation of teachers for teaching STEM and sustainability (Ferreira et al., 2019; Imara & Altinay, 2021; UNESCO, 2018), or developing students' 21st-century knowledge and skills (Ellis & Williams, 2020; Greenhill, 2010). Only one framework addresses cross-curriculum teaching competencies in general (Timmerman, 2019a). These frameworks broadly represent two approaches: 1) person-oriented, and 2) system-oriented. Respectively, they foreground the 'what' and 'how' aspects of developing teacher expertise.

Interdisciplinarity in the Australian Professional Standards for Teachers

The Australian Professional Standards for Teachers include three main areas that partly relate to teachers' interdisciplinary expertise:

- 1) The ability to make content meaningful for a diverse range of students.
- 2) The use of a range of effective teaching strategies, including those that encourage problem solving and critical thinking.
- 3) The ability to use ICT in teaching.

There is a strong focus on the teacher's ability to plan, create resources, take the initiative, be flexible, and use research.

Interdisciplinary, cross-curriculum, or other integrated kinds of teaching and learning are not explicitly mentioned, and the document does not provide more detailed guidance about teacher capabilities in this area.

Box 1: Interdisciplinarity in the Australian Professional Standards for Teachers (Australian Institute for Teaching and School Leadership [AITSL], 2011)

Person-oriented (or competence-oriented) frameworks take an individual approach and foreground teacher functional abilities (also known as competencies) necessary for interdisciplinary teaching. Such frameworks offer detailed lists of the competencies that each teacher should develop and demonstrate. For example, the "CrossCUT Reference Framework for Cross-Curricular Teaching" maps common competencies of cross-curricular teaching that broadly cover three spheres: 1) working with knowledge, information and technology; 2) working with others; and 3) working with society (A, 2019b). They include

14 competencies and 193 specific areas of teacher knowledge, skills, responsibilities and autonomies.

System-oriented (activity-oriented) frameworks focus on the outcome and process of learning within a larger system. They describe what teachers should be capable of knowing and doing and why, but emphasise a holistic vision, principles and processes distributed across the system. They attribute capability less to an individual teacher than to the entire distributed activity system. For example, the UNESCO (2018) model for the integration of Education for Sustainable Development in teacher education sketches nine main elements of the framework grouped into three areas: conceptual core, practice, and context. It emphasises the holistic, interconnected and contextual nature of learning and, therefore, details an action-oriented approach that: “positions both leaders and teachers as co-learners while taking action for the transformation of society” (p. 21).

Two critical tensions can be observed in the majority of current frameworks that describe what constitutes teachers’ expertise for interdisciplinary teaching. First, what are the distinct aspects of expertise that are needed for interdisciplinary teaching? Some frameworks and literature include capabilities (such as teacher digital capabilities, communication, and cross-cultural competencies) that are not specific to interdisciplinary teaching (Timmerman, 2018). However, other literature argues that interdisciplinary teaching requires distinct capabilities, such as ‘knowledge integration’ (Krug & Shaw, 2016).

Secondly, what kinds of disciplinary expertise do teachers need, particularly when they teach in interdisciplinary teams? Some literature suggests that teaching interdisciplinary curricula and collaborating in interdisciplinary teams involves particular kinds of expertise in one’s core discipline as well as in other (integrated) disciplines (Grossman et al., 2001; Timmerman, 2018). However, there is rarely any discussion of how this particular expertise differs from the disciplinary expertise that subject teachers possess.

Insights from researching interdisciplinary expertise in multidisciplinary laboratories

Research on what constitutes interdisciplinary expertise in multidisciplinary research settings shows that this expertise can be understood by looking across three levels of interdisciplinary practices (Figure 2):

- *Micro: personal resourcefulness* involves knowledge, skills, dispositions, and other individual resources to engage in interdisciplinary practices;
- *Meso: distributed activities* involve capabilities distributed among people and tools to carry out interdisciplinary work collectively in a setting; and
- *Macro: knowledge cultures and contexts* involve capabilities to navigate across, interact with, and shape various aspects of interdisciplinary practices that extend beyond the immediate setting of activity (policies, communities, institutions, etc.).

Discussion questions

1. What are the key aspects of teachers’ expertise for interdisciplinary teaching at the macro (system, school), meso (curriculum, classroom) and micro (personal—knowledge, skills, dispositions, agency) levels?
2. What kinds of environments and contexts are necessary for interdisciplinary teaching?

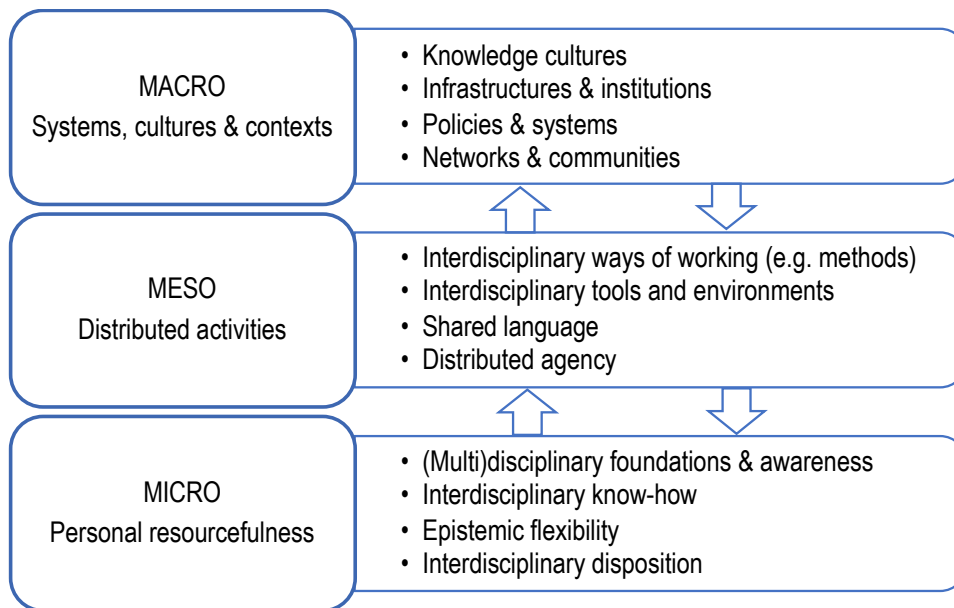


Figure 2: Layers of interdisciplinary expertise in research practices

Question 3: What are the key features of effective professional education for interdisciplinary teaching?

Literature shows that pre-service and in-service teachers' professional development for interdisciplinary teaching includes a range of models (Enderson et al., 2020; Evans, 2019; Grossman et al., 2001; Imara & Altinay, 2021; Jenlink & Jenlink, 2019; Krug & Shaw, 2016; Liu, 2020; Luft et al., 2020; Quan et al., 2019; Wojnowski & Pea, 2014).

Examples include:

- *Standalone interdisciplinary modules or courses* to develop teachers' interdisciplinary capabilities for integrative cross-curriculum teaching, such as the CrossCUT online course (Timmerman, 2019b), and many sustainability-oriented programs (Imara & Altinay, 2021).
- *Embedding interdisciplinary focus and connections within or across existing subjects*, for example, making connections to mathematics in science courses and connections to science in mathematics courses (Watanabe & Huntley, 1998).
- *Embedding interdisciplinary focus in professional learning community activities*, for example, joint discussions of history and English literature readings to create an interdisciplinary humanities curriculum (Grossman et al., 2001).
- *Project-based courses or modules*, where pre-service or in-service teachers learn through practical hands-on projects, such as co-creating integrated curricula and co-teaching (ACARA, 2016; Ryu et al., 2019).
- *Short experiential interdisciplinary learning opportunities*, such as hackathons for planning interdisciplinary curriculum modules or expert-modelled integrated days (Harvey & Reid, 2001; Milara et al., 2020).
- *Professional learning alongside students' interdisciplinary project-based learning*, for example, when students' projects involve partnerships with experts from research organisations, museums or zoos.
- *Different combinations of the above and other models*, such as participatory action research with university partners (Hunter, 2020) or intensive professional development sessions combined with teaching and ongoing mentorship (Anderson & Tully, 2020).

Specific programs vastly differ in their duration, the number of participants, included disciplines, and other key characteristics; for example, some courses are two-hour individually completed online modules, while others are learning communities that last for more than two years. The rationales behind the choice of a particular model and specific design decisions are rarely made explicit in the literature. Therefore, it is not always clear why teacher educators and educational institutions make these design choices and how they align their chosen models with specific needs or contexts.

Many of the design principles used for designing interdisciplinary courses tend to be similar to those principles that are known to be effective for designing teacher professional development in general, such as: 1) being content focused; 2) incorporating active learning; 3) supporting collaboration; 4) using models of effective practice; 5) providing coaching or expert support; 6) offering feedback and reflection; and 7) being

of sustained duration (cf. Darling-Hammond et al., 2017; Luft et al., 2020). Specific pedagogies vary, but as a rule, they relate to authentic, teacher-as-learner-centred participatory approaches (Box 2). The question of what is distinct to effective teacher education for interdisciplinary teaching and how to make productive design decisions remains important.

Pedagogical approaches in teacher education programs for interdisciplinary teaching

- *problem-based learning* focused on themes important in a local context (e.g., air pollution);
- *project-based-learning* while engaging with a local community or external partners;
- *site visits*, field trips and other kinds of experiential learning;
- *learning through social action*, such as engagement with issues of justice in STEM, teacher-led hackathons and other activist approaches;
- *immersed professional learning* as a part of institution-wide transformations, such as the global EcoSchools program.

Box 2: Examples of common pedagogical approaches

Despite a huge variety of models and programs for professional teachers' learning related to interdisciplinary teaching, the literature reports very positive outcomes (Ellis & Williams, 2020). However, much evidence focuses on evaluations of specific professional education programs and often comes from participants' self-reported immediate feedback about their course experiences and outcomes. There is much less evidence about transfer, sustainability and broader long-term impact (Luft et al., 2020).

Current reports describing designs of pre-service and in-service programs rarely engage with epistemological, theoretical, or pedagogical questions about the unique features of different interdisciplinary knowledge practices and how people learn to work across particular knowledge boundaries. For example, reports rarely make a clear distinction between horizontal integration across disciplines and vertical integration between theoretical knowledge and its application in solving practical, real-world challenges. They are also rarely explicit about the relationship between general capabilities and diverse disciplinary and interdisciplinary practices. Integration is often seen as the only possible mode for bringing disciplines together. It is far less common to engage teachers in explicit discourse and reflection on underpinning assumptions and different ways of doing interdisciplinarity. There is a concern that this translates into confusion and inadequate, mainly instrumental, interdisciplinary teaching practices. For example, a research literature review of STEAM practices observed that many educators struggle to understand how creativity is fostered and "While STEAM programs often incorporate problem-based approaches, the design-process, or hands-on experiences, they often overlook the key aspects of arts education which include critique, self-expression, and conveying meaning" (Perignat & Katz-Buonincontro, 2019, p. 41).

Insights from researching interdisciplinary learning in multidisciplinary laboratories

Findings from interdisciplinary research settings converge on three key aspects of productive practices and arrangements that facilitate interdisciplinary learning:

- *Characteristic epistemic activities*—sometimes called ‘epistemic games’ (Perkins, 1997)—that facilitate interdisciplinary knowledge work at different stages of the projects, such as techniques for exploration of problems from different perspectives, generation and integration of ideas, and transformation of conceptual solutions into actionable outcomes and tangible products (Markauskaite & Goodyear, 2017). For example, innovation teams use diverse characteristic design-thinking activities—from considering context to evaluating outcomes—when designing new services and products (Straker et al., 2021)
- *Shared infrastructures and objects* that mediate collaboration, knowledge sharing, advancement of ideas and production of joint outcomes. For example, much of interdisciplinary work is done by using shared conceptual, digital and material tools, assembling resources, and co-constructing characteristic knowledge objects (concept maps, models, prototypes, etc.) that help make ideas visible and give materiality and concreteness to joint knowledge work (Nersessian, 2019a; Nicolini et al., 2012).
- *Epistemic awareness and joint apprenticeship*, which includes team capabilities to help each other recognise and understand different perspectives, kinds of knowledge and ways of knowing as well as move across each other’s specialised ‘languages’ when engaging in joint knowledge work (Hubbs et al., 2021; Nersessian, 2019b). For example, some research teams engage in philosophically structured dialogue-based activities designed to enhance mutual understanding of each other’s ways of thinking and communication in complex multi-disciplinary projects (Hubbs et al., 2021).

Discussion questions

1. What are examples of successful teachers’ professional learning for interdisciplinary teaching from your practices?
2. What models have been embraced by your institution for preparing teachers for interdisciplinary teaching? Why?
3. What design principles or features have been most critical for the effectiveness of teachers’ learning for interdisciplinary teaching? Why?

Question 4: What are the main barriers and enablers for developing pre- and in-service teachers' expertise for interdisciplinary teaching?

Educational research in this area has mainly been focused on barriers to interdisciplinary teaching in schools. There is much less literature on barriers to developing expertise for interdisciplinary teaching. Those discussed in the literature are mainly associated with three aspects: 1) broader environments, including structural, organisational, and epistemic aspects; 2) participants, including constructs related to teachers, teacher educators and other collaborators and stakeholders; and 3) relational aspects, including power and other entwined relationships among the above (Figure 3). Most of the mentioned enablers are opposites to the barriers (e.g., no time vs. a dedicated time for interdisciplinary collaboration). That is, they are predominantly related to the absence of constraints. However, some enablers are related to additional facilitating factors or conditions (e.g., collaboration with academic mentors during professional development). The text below elaborates on each aspect. Table 1 presents examples of barriers reported in studies of STEM education in the Australian context.

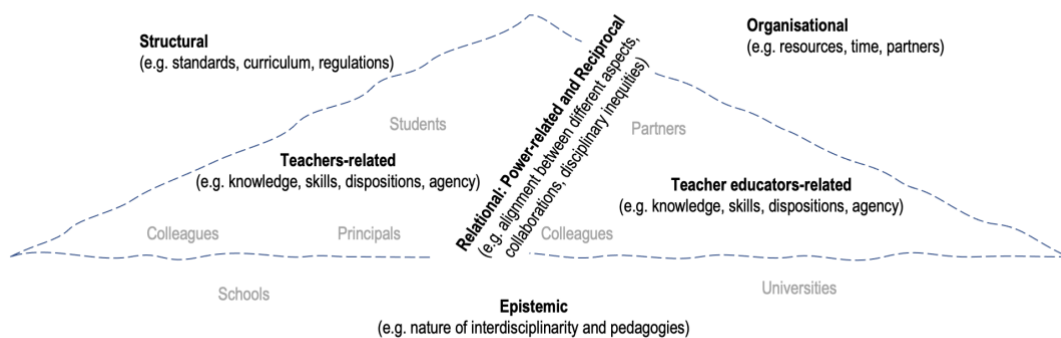


Figure 3: Barriers and enablers in developing expertise for interdisciplinary teaching

Environment-related barriers and enablers

Structural barriers are related to different regulations shaping teachers' preparation for interdisciplinary teaching and tensions emerging between them. Examples include the unclear role of interdisciplinary teaching and learning in professional teacher standards and teacher education programs that are overcrowded with disciplinary content (Enderson et al., 2020, p. 349). Policies promoting integrated teaching and learning, such as the National STEM school education strategy (Education Council, 2015), are seen as important enablers. However, misalignments between various regulations create unproductive tensions, such as tensions between policies promoting professional education for interdisciplinary education (e.g., STEM, general capabilities) and a strong disciplinary focus in high-stakes tests and examinations (Ellis & Williams, 2020).

Organisational barriers are related to practical arrangements embedding interdisciplinary aspects in pre- and in-service teacher education, such as: the time needed for academics to develop high-quality courses for interdisciplinary teaching; lack of funds or other resources; lack of time and space for interdisciplinary professional learning; challenges establishing sustainable partnerships and sustaining continuous professional learning (ACARA, 2016; Enderson et al., 2020; Ferreira et al., 2019; Tytler, et al., 2019). Typical organisational enablers are related to a dedicated time for teachers and teacher educators to learn, collaborate and plan interdisciplinary curricula (ACARA, 2016; Harvey & Reid, 2001; Timmerman, 2018).

Epistemic barriers are related to the nature of interdisciplinary knowledge practices and pedagogies for developing students' capabilities to work across disciplines. Examples include: the distinct nature of knowledge, knowledge practices and language in each discipline, and the distinct role of each discipline in integrative knowledge practices (Couso & Simarro, 2020; Liu, 2020); the diversity of purposes behind integrative teaching (Wojnowski & Pea, 2014); lack of clarity about integrative pedagogies (Perignat & Katz-Buonincontro, 2019) and about how each discipline should be taught in integrative curricula (Enderson et al., 2020). In contrast, epistemic clarity about the purposes of interdisciplinary teaching, and deep teacher engagement with epistemological and pedagogical questions, are conditions supporting teachers' interdisciplinary learning (Grossman et al., 2001; Harvey & Reid, 2001).

Participant-related barriers and enablers

Participant-related barriers and enablers are associated with the resourcefulness of people involved in interdisciplinary teaching and learning, including the knowledge, skills, dispositions and other experiences that they bring to interdisciplinary education settings. Teachers and teacher educators are at the heart of this, with a number of other participants and stakeholders being important contributors to how teachers engage in interdisciplinary professional learning and teaching.

Teacher (as a learner)-related barriers concern teacher knowledge, skills and dispositions (beliefs, motivation, agency) necessary to engage in learning for interdisciplinary teaching: lack of interest or willingness on the part of teachers to engage in interdisciplinary learning (Timmerman, 2018); teachers feeling sceptical, insecure and reluctant to engage in interdisciplinary education (Ellis & Williams, 2020); lack of teacher confidence in their abilities; lack of awareness and understanding of curriculum requirements of other subjects (Timmerman, 2018); lack of subject knowledge (Hunter, 2020). Reported enablers are mainly associated with similar aspects, such as: appreciation of the importance of interdisciplinary teaching; understanding and insight into other subjects/disciplines; open-mindedness and willingness to collaborate and learn about other disciplines (Harvey & Reid, 2001; Timmerman, 2018). One of the distinct enablers is pre- and in-service teachers' personal resourcefulness developed through personal daily lives, such as "experiences as a student, personal interests, and their disciplinary identities" that provide a foundation for interdisciplinary teacher learning (Ryu et al., 2019, p. 502).

Teacher educator-related barriers concern teacher educators' knowledge, skills and dispositions to prepare teachers for interdisciplinary teaching: teacher educators' knowledge and confidence in making connections to the disciplines beyond their core expertise; seeing interdisciplinary connections as adds-on to discipline-focused teacher education (Watanabe & Huntley, 1998); philosophical differences about interdisciplinarity between teacher educators and their scepticism about the value of interdisciplinary teacher education (Harvey & Reid, 2001); lack of training and expertise of interdisciplinarity and interdisciplinary pedagogies when developing teacher education programs (Enderson et al., 2020). Enablers often relate to teacher educators' positive disposition towards interdisciplinary education and resilience in the presence of various barriers (Harvey & Reid, 2001).

Stakeholder- and other contributor-related barriers and enablers related to other participants, such as school and university leaders, external partners, and students, who contribute in their roles to interdisciplinary teaching and learning activities. For example, the lack of school leadership, school students' and even parents' support of interdisciplinary learning are barriers to teachers' professional learning in this area (Hobbs et al., 2019). Further, in contrast to subject-focused professional education, interdisciplinary teacher education usually involves collaborations and partnerships between tertiary institutions, schools and external partners from industry, community or research organisations. For example, the presence of tertiary mentors in school-based professional development programs is an enabler. Simultaneously, the literature points out obstacles and tensions. For example, "disciplinary egocentrism", which is described as a lack of students' readiness to engage in multidisciplinary education, as MacDonald et al. (2019) argue, "can also be applied to a wide range of key education stakeholders, such as teachers, academics and indeed STEAM industry experts who are unable or unwilling to value alternative approaches to their respective discipline areas (Yoder, Bodary & Johnson, 2016)." (p. 76).

Table 1: Examples of barriers discussed in the context of STEM education in Australia

Barriers	Examples from the Australian STEM context
Environment-related	
Structural	The National STEM Education Strategy promotes teachers' professional development in STEM, but STEM is absent from the Australian National Curriculum in terms of a recognised learning area or a cross-curricular priority; there is no explicit emphasis on interdisciplinary teaching in the Australian professional standards for teachers (Ellis & Williams, 2020).
Organisational	ACARA's STEM Connections report observes that interdisciplinary projects "can have significant implementation issues, regardless of the implementation model, in traditional school settings, as timetabling structures do not necessarily have the flexibility to accommodate such projects" and this "can result in inconsistent content coverage" (ACARA, 2016, p. 19).
Epistemic	A STEM project reports "tensions arising between: criterion based assessment versus descriptive assessment; a focus on disciplinary content versus STEM practices or inquiry processes; and a focus on reporting versus a focus on student engagement." (Hobbs et al., 2019, p. 224)
Participant-related	
Teacher-related	Not all teachers are equally enthusiastic about STEM: "Educators working within technology education have indicated that they feel threatened by STEM education"; and some teachers in Australian schools feel "threatened by the inequity of STEM, or as an alternative to replace disciplinary subjects" (Ellis & Williams, 2020, p. 430).
Teacher educator-related	Academics do not always have a disposition (willingness or ability) to value alternative disciplinary perspectives and world views (MacDonald et al., 2019).
Participant and stakeholder-related	Challenges "convincing school leadership, other teachers, students and even parents of the value of rethinking the curriculum to include STEM learning opportunities" (Hobbs et al., 2019, p. 225).
Relational	
Power-related	Commonly observed power-related barriers in Australian STEM include: general inequity among disciplines in the Australian Government's STEM documents (Barlow & Ellis, 2016); more central role of science in an integrated approach to STEM education and lack of clarity about the role of technologies (Ellis & Williams, 2020); and significant "gender gap" (Ellis & Williams, 2020)
Reciprocal	Challenges "associated with school-industry collaborations when attempting to make links between school content and the world of work"; "teachers and industry representatives often do not share a common language, and the language of industry may not be understandable for students" (Hobbs et al., 2019, p. 225).

Relational barriers and enablers

Various barriers and enablers are often interrelated and rarely encountered in isolation; and many tensions emerge at the intersections of personal learning for interdisciplinary teaching and environment-related aspects. For example, a study on teacher sustainability education points out, “Research indicates individual teacher educators are motivated to change and have the ability to incorporate EFS [Education for Sustainability] (Steele, 2010). The greatest constraint is providing overall systemic support for such changes to happen.” (Ferreira et al., 2019, p. 56). Most barriers and enablers are related either to hierarchical power relations or to more horizontal and reciprocal relationships.

Power-related barriers concern broader cultural stereotypes, political decisions and agendas that influence the distribution of social and epistemic power, create inequities, and result in negative responses and tensions. For example: disciplines (subjects) are not positioned as equally important (English, 2016; Liu, 2020); not all subjects are included or have equal roles in the interdisciplinary curriculum; interdisciplinary education is seen as competing with disciplinary teaching (Ellis & Williams, 2020); vocational skills and general capabilities are considered less important than academic subjects (Masters, 2020) (see Box 3). Explicit arrangements that promote epistemic and social equity, such as inclusivity of all disciplines and non-academic perspectives, as well as transformational pedagogies that expose and engage teachers with the issues of gender, cultural and racial diversity, are seen as enablers helping develop awareness and greater inclusivity in interdisciplinary teaching (Quan et al., 2019).

Skills in applying knowledge

“In the current school curriculum, the acquisition of skills is often treated differently from the acquisition of knowledge, and given a lower priority. This is particularly true in the later years of school where subjects are divided into academic subjects focused primarily on providing a knowledge base for further learning of a subject, and vocational subjects focused primarily on providing skills for particular occupations. But it is also reflected in approaches to general capabilities, which are often treated as conceptually different from, and *less important than*, disciplinary knowledge.”

Box 3: Examples of power-related barriers from the NSW curriculum review (Masters, 2020, p. 87)

Reciprocal barriers and enablers are related to alignments within and across the contextual and human-related aspects, joint learning and systemic change: collaborating and learning in multi-disciplinary teaching teams; overcoming challenges of ‘siloed’ school and university structures; understanding each other’s languages; creating collaborations and partnerships with external partners; collaborating with colleagues involved in similar interdisciplinary teaching practices in other institutions, involving other colleagues, designing curriculum that can be enacted within the existing conditions, learning and change for interdisciplinary teaching across all levels of the system (ACARA, 2016; Mohamad Hasim et al., 2022; Tytler et al., 2019).

Critical tensions

Different aspects are interrelated, and enabling conditions are rarely a simple sum of its parts. Two overarching tensions emerge from synthesis:

The tension between curriculum/logistical and epistemic/relational aspects in teacher education programs. Pre-service and in-service teacher education programs for developing teacher interdisciplinary expertise for interdisciplinary learning often are project-based and focus on pedagogical and logistical aspects of interdisciplinary curriculum development and implementation (e.g., by organising teachers' learning through collaborative lesson planning and implementation projects) (Luft et al., 2020). In contrast, the literature suggests that some critical barriers and enablers are related to epistemic and relational aspects, such as teachers' philosophical dispositions towards interdisciplinary education (Harvey & Reid, 2001), the need for teachers' deeper understanding of disciplines and interdisciplinarity (Ryu et al., 2019), understanding external partners' language (Hobbs et al., 2019).

The tension between the focus on institutional mainstreaming vs. teacher flexibility. The scalability, adaptability to change and sustainability of interdisciplinary teaching practices are often seen as critical aspects for the broader adoption of interdisciplinary education; and success is often attributed to the overall system's capability to achieve institutional mainstreaming (Ferreira et al., 2007). Beyond some research on the transfer of learning from professional education programs to classroom practices (Luft et al., 2020), there is far less discussion about how to develop teachers' flexibility to engage in interdisciplinary teaching practices across diverse (social, material and epistemic) settings and changing contexts.

Discussion questions

1. What are the main barriers and enablers for developing pre- and in-service teachers' expertise for interdisciplinary teaching in the NSW context?
2. How could pre- and in-service teacher education prepare teachers to address larger structural, organisational and epistemic barriers?
3. How could teacher education develop teachers' flexibility and adaptability to engage in interdisciplinary teaching in diverse and changing contexts?

Methodology⁴

This part of the report presents key insights from the consultation interviews, where invited participants with relevant expertise and experience shared their knowledge in response to the consultation presented in the first part of the report. Data collection involved consultation interviews conducted between 8 December 2022 and 21 June 2023. Purposeful sampling was used, aiming to invite participants who have relevant expertise.

To identify the most relevant participant groups, the project team, with the Project Reference Group, mapped the main informant and stakeholder groups (Figure 4). It was decided to invite more participants from the central informant and stakeholder group: teacher educators, school leaders, teachers, and student teachers. Participants were recruited via the research team's initial contacts, the Project Reference Group and by following up participants' recommendations. People from the central informant and stakeholder group were identified and invited first. These individuals have multiple roles and can represent the views of other stakeholder groups; they include, for example, student teachers who are also grassroots organisation leaders, and teacher educators who are also leading professional associations. Next, teacher educators from each NSW university and other recommended participants were invited.

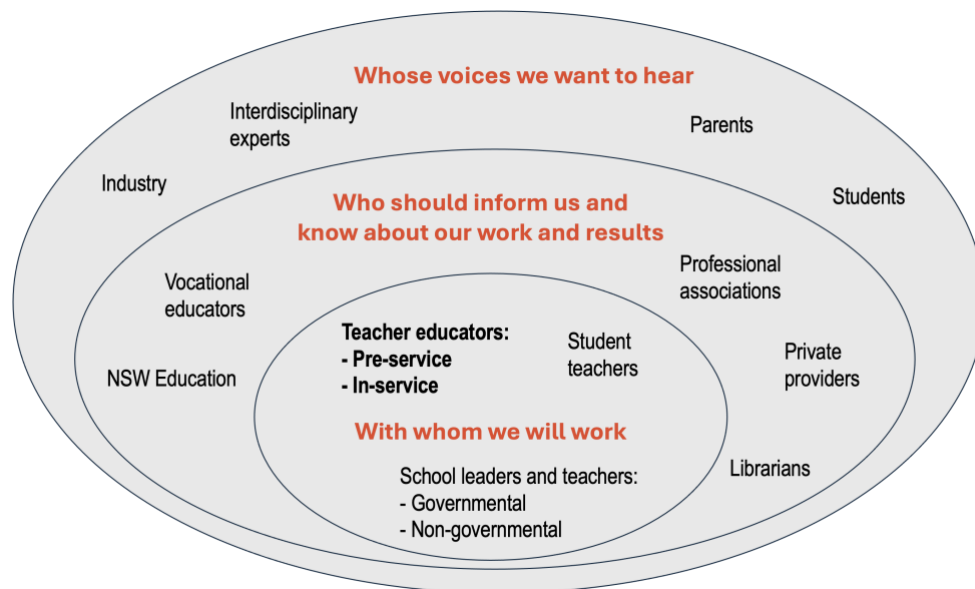


Figure 4: Project informant and stakeholder map

In total, 23 consultation interviews were conducted. The participants included teacher educators (n=12), leaders and teachers from governmental and non-governmental NSW schools (n=3 and n=2, respectively), student teachers (n=2), Department of Education representatives (n=2), and professional learning providers (n=2).

Semi-structured consultation interviews ranged in duration from 30 to 70 minutes. The interview schedule (summarised in Box 1) gathered background information (including a

⁴ The rest of this report is based on Markauskaite et al. (2023b).

question about the meaning of interdisciplinarity for the person being interviewed), posed four questions drawn from the Consultation paper developed as part of this study (Markauskaite et al., 2023a), and made space for final comments. All participants were provided with the Consultation paper several days before the interview. All but one of the interviews were audio-recorded and detailed notes were taken.

Background information

- Could you please describe your current role/work?
- What interdisciplinary aspects does your role/work involve (if any)?
- What does interdisciplinarity mean to you?

Consultation questions detailed in the consultation paper

1. What are the most important areas of teachers' interdisciplinary practices and needs for professional learning?
2. What kind of expertise and resources do teachers need for productive interdisciplinary teaching)?
3. What are the key features of effective professional education for interdisciplinary teaching?
4. What are the main barriers and enablers for developing pre- and in-service teachers' expertise for interdisciplinary teaching?

Final comments

- Are there any additional aspects about developing teachers' interdisciplinary expertise which we haven't covered—and that you'd like to share?

Box 4: Consultation interview schedule

Data analysis focused on identifying key insights in response to the question about the personal meaning of 'interdisciplinarity' and each of the four consultation questions. The interview notes were analysed using thematic analysis. This was synthesised across the five areas, focusing on the implications for pre-service and in-service education (Figure 5). The main findings are presented in the next section and summarised in Appendix 2. The quotes are based on the researchers' notes; they aim to convey the gist and are not verbatim.

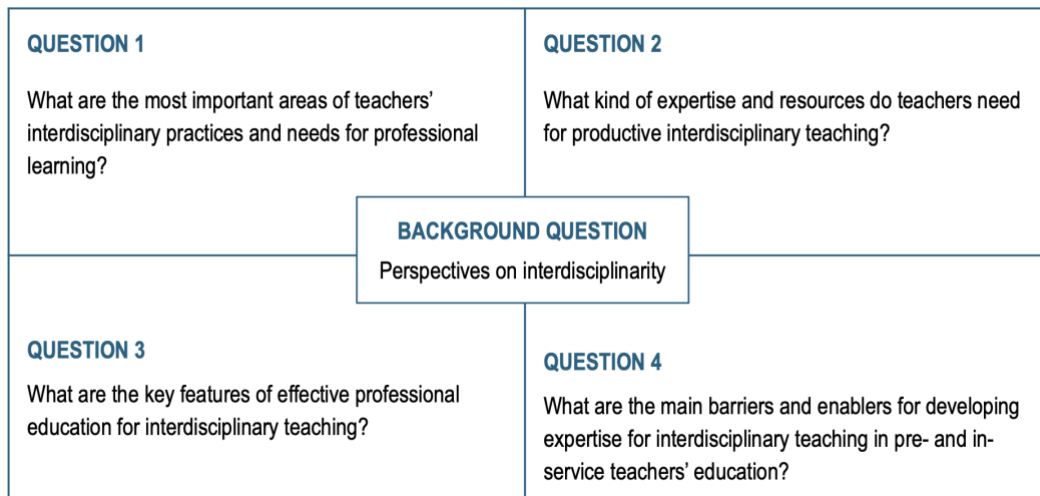


Figure 5: Framework for synthesising findings

Main findings

Background question: Perspectives on interdisciplinarity

The participants responded to the question ‘What does interdisciplinarity mean to you?’ by describing knowledge and personal attributes necessary for engagement in interdisciplinary practices. They broadly covered seven interrelated dispositions:

- disposition to connect subjects;
- disposition to be transformative;
- disposition to be faithful to knowledge;
- disposition to be adaptive;
- disposition to be relational;
- disposition to be action-oriented; and
- disposition to be purposeful.

Each disposition encompassed a set of interrelated constructs, such as knowledge, skills, beliefs, values, and inclinations. Some dispositions were general to interdisciplinary practices, while others were specific to interdisciplinary teaching.

Disposition to connect subjects involves the capability and inclination to work across disciplines, move beyond subject ‘silos’ and disciplinary ‘bunkers’: connect, leverage and merge subjects towards a holistic understanding of a phenomenon; connect learning across the curriculum; and build relationships between subjects. The participants described interdisciplinarity as ‘crossing between disciplines, tools, and methods’, ‘combining many KLAs (key learning areas) and outcomes’ and ‘making as many links as possible’.

Disposition to be transformative involves the capability and inclination to work beyond the comfort zone. The participants observed that interdisciplinarity requires fearlessness and resilience: ‘not afraid to try new things’, ‘having courage to give it a go’, ‘role-modelling that it’s ok to fail’, and ‘being open and vulnerable’. In educational settings, it also involves trusting students: ‘a belief that teenagers can do good stuff, take down barriers to let them fly’; ‘imagination, willingness to trust the kids’.

Disposition to be faithful to knowledge involves teachers’ capability and commitment to engage with knowledge deeply. The participants pointed out that ‘interdisciplinarity is a body of knowledge and ways of knowing’ and ‘understanding knowledge is critical to work and think in interdisciplinary ways’. Deep understanding of disciplines is central in interdisciplinary practices; it involves ‘appreciation of a number of different discipline areas’. They also observed that ‘interdisciplinarity brings knowledge together—so things become deeper’. However, the participants emphasised the importance of retaining the integrity of individual disciplines and the intellectual quality of interdisciplinary teaching: ‘not watered down, but faithful’.

Disposition to be adaptive focuses on the inclination to be flexible and the capabilities to engage in curriculum-making and tailor the curriculum for specific contexts. Interdisciplinarity is to have transferable skills, such as ‘problem-solving’, ‘critical thinking, researching, finding, and engaging’. A significant aspect is teachers’ mastery of curriculum-making strategies and pedagogies that underpin interdisciplinary teaching and require teacher flexibility: such as inquiry, problem-based learning or capability-focused learning through solving problems that pull in several disciplines.

Disposition to be relational includes capabilities and inclination to engage with uncertainty by collaborating with colleagues specialising in various subjects and with diverse stakeholders. The participants emphasised that interdisciplinarity is a process

characterised by ambiguity, disparate interests, values, and needs, including disciplinary hierarchies, power relationships, personalities, money, and goals. Therefore, this process requires negotiation. An essential aspect of this disposition is the capability and willingness to collaborate: ‘working together, with different teachers, who teach in different disciplines’; ‘being able to provide opportunities for people to collaborate between departmental areas or specialist subject areas’. The participants noted tensions, power and hierarchies between disciplines and school subjects. They emphasised the importance of respecting diverse disciplinary ways of knowing and embracing diversity, including epistemic diversity: ‘maintain and respect particular disciplines’, and ‘negotiating to make epistemic space between disciplines’.

Disposition to be action-oriented includes capabilities and inclinations to embrace teaching approaches that focus on learning through doing and engagement with real-world issues within the context. The participants described interdisciplinarity as ‘doing something that makes sense in the world’. The participants emphasised that it is vital for teachers to create opportunities for the students to engage with global issues and wicked problems, such as climate change, sustainability, and energy consumption. As they noted, ‘saying it is in the curriculum is not enough’; teachers must create space for students to pursue their interests and personal challenges: ‘meaningful experiences and what is required to live a good life’.

Disposition to be purposeful includes the capabilities and inclination to be accountable for and support students’ learning and understanding through creating an appropriate scaffolded environment. This disposition includes learning to be a guide or a coach and, when necessary, ‘walk’ with the students by giving them ‘scaffolds’ and ‘goalposts’. It also includes teachers’ capabilities to know when explicit teaching is appropriate and use these strategies to help students master specific knowledge and skills. The participants observed that explicit teaching could be necessary for assisting students to make connections, so they saw how different disciplines come together but simultaneously understood each discipline’s uniqueness and the ways of knowing in that discipline.

Overall, the participants observed that interdisciplinarity ‘is a very ambiguous frame of reference for educators’. Figure 6 summarises the main interdisciplinary dispositions emerging from the interviews.

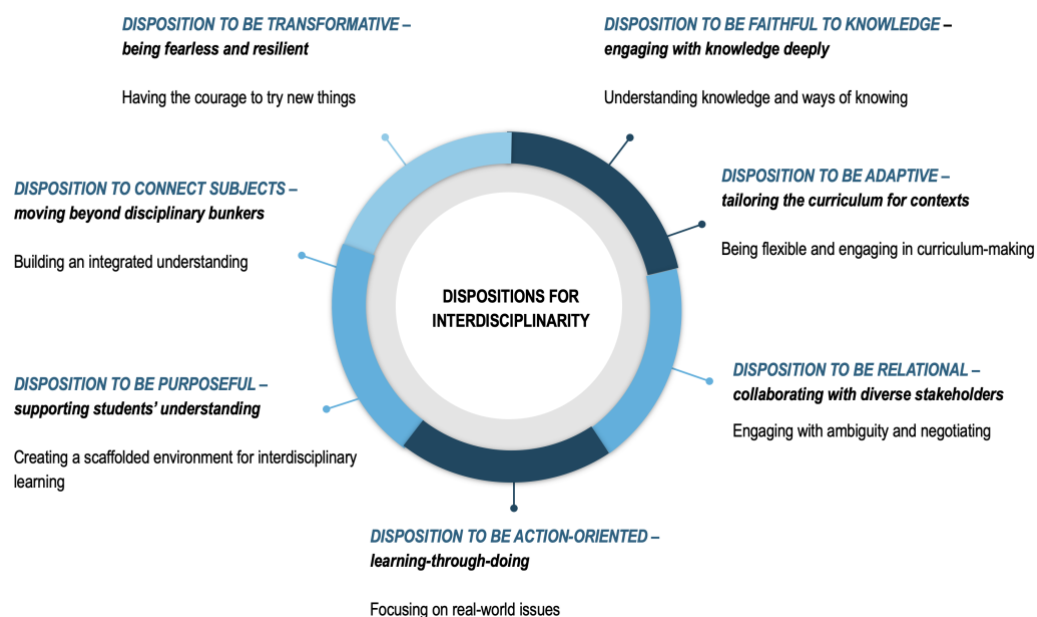


Figure 6: Dispositions for interdisciplinarity

Q1: Areas of teachers' interdisciplinary practices and needs

Six themes dominated in the participants' responses to the first consultation question: 'What are the most important areas of teachers' interdisciplinary practices and needs for professional learning?'. They were:

- identifying 'launchpads' to branch out when engaging in interdisciplinary teaching;
- developing (inter)disciplinary fluency and addressing assumptions, biases, habits and fears;
- utilising pedagogical approaches that support breaking down subject boundaries;
- engaging with and shaping the curriculum in creative ways;
- tailoring to pre- and in-service education needs and targeting workforce issues; and
- collective capacity-building, learning and safety.

Identifying 'launchpads' from which to branch out when engaging in interdisciplinary teaching is the starting point when creating an interdisciplinary curriculum. Sustainability, pollution, climate change, food scarcity, complex politics, use of AI, and other global challenges offer such launchpads. As some participants observed, young people are interested in solving these challenges. Further, when ideas connect to each other and to real-world issues, and relate to an activity, then students understand and remember them better. Some participants also mentioned that such 'launchpads' could also be found in workplace practices and everyday life, such as teaching e-commerce with the online market, exploring real-world data, and providing possibilities for students to create specific products that are meaningful for them. Identifying launchpads is not necessarily easy. Some subjects almost naturally contain them (e.g., computing is mainly taught through project work), whereas others require teachers' expertise and effort (e.g., mathematics).

Developing (inter)disciplinary fluency and addressing assumptions, biases, habits, and fears were among the main themes in the participants' descriptions of teachers' needs for professional learning. The participants observed that teachers often have training in a particular discipline, but they do not feel comfortable working in other disciplines, struggle to see how to draw them together, and even fear to do so. They noted that teachers have 'subject area hats' and often want to be at the centre of the stage and control the basis of their curriculum. Interdisciplinary teaching requires recognising an increasingly connected and complex world with diverse 'mindsets'. As the participants mentioned, it is vital to recognise the limits of disciplinary paradigms. A big part of interdisciplinary practices is finding ways to loosen tight boundaries around subjects and to develop an appreciation of different disciplinary areas.

Utilising pedagogical approaches that help break down subject boundaries. While interdisciplinary practices are usual in early childhood and primary settings, they are not necessarily common or encouraged in secondary settings, and secondary school teachers do not always have the necessary pedagogical knowledge and skills. There is a need to shift towards more facilitative pedagogical models, such as problem-based learning, inquiry, connected learning, project-based learning, collaborative learning, and group work. Teachers need opportunities to learn about how to integrate different subjects. The participants noted that there are immense opportunities, even in individual subjects, to introduce interdisciplinary components; for example, English and literacy transcend all discipline areas. The participants suggested that teachers could learn from the curriculum areas where some components of interdisciplinary teaching already happen. Interdisciplinary teaching requires thinking beyond one subject space and understanding that the teacher's role is not to transmit, but to engage with, knowledge.

Engaging with and shaping the curriculum in creative ways. Interdisciplinary teaching involves working with the curriculum more creatively and collaboratively; for example, by finding subject interrelationships and points of interest and developing joint lesson sequences. Formal, subject-based curriculum outcomes could be a constraint for interdisciplinarity, but teachers could transform these curriculum constraints into opportunities. For example, some participants said that they look for inspiration for interdisciplinary lessons in curriculum documentation by searching for intersecting themes beyond their subject. The participants mentioned the potential of various design-based professional learning and curriculum co-development models, including various innovative and engaging forms, such as hackathons for joint planning of lesson sequences. The participants also noted that even more possibilities open up when teachers learn to create industry links. Further, programs should not be fixed; a part of teacher practice is to focus on students' needs and the continuum of learning and progression.

Tailoring to pre- and in-service education needs and targeting workforce issues. Teachers have very different levels of expertise and experience engaging in interdisciplinary teaching. Therefore, professional education should be varied and designed for diverse levels, needs and experiences. In pre-service education, it is important to help student teachers master problem- and inquiry-based pedagogical models that are central when adopting interdisciplinary approaches. In in-service professional learning contexts, teachers may need guidance to problematise their practice, e.g., by prompting them to focus not just on the high-quality technical delivery of their subject but also on broader educational questions. Further, a significant proportion of teachers are not trained in their subject; because of this, they may not understand the subject that deeply and have different challenges embracing interdisciplinary approaches from those who are disciplinary experts.

Collective capacity-building, learning and safety. Interdisciplinary teaching practices are collective; they involve breaking down subject barriers, finding a way to learn together, and teaching each other. Teachers need spaces for collaboration, hands-on work and time to engage in professional learning communities and put ideas into practice. It is vital for teachers to feel safe when engaging in interdisciplinary practices and have opportunities to talk with others about what they had in mind, how they thought about something, what they noticed, how they are feeling, and why they feel that way. Teachers' emotions and psychological safety, interests and engagement via personal exploration are critical.

Overall, interdisciplinary teaching practices are challenging, and teachers need professional learning to apprehend and model them. It is essential to challenge and empower teachers to work beyond (curriculum) compliance, focusing on developing them as resourceful professionals who build their knowledge and skills over time through ongoing spiral learning. Such learning could begin by helping student teachers to master simple, easily achievable pedagogical ideas for interdisciplinary teaching that are later revisited and expanded into more comprehensive pedagogical models.

Q2: The expertise and resources for productive interdisciplinary teaching

Research on what constitutes interdisciplinary expertise in multidisciplinary research settings shows that this expertise is not only a personal construct but also a characteristic of a multilayered distributed activity system (Markauskaite et al., 2023a). Such expertise can be understood by looking across three levels of interdisciplinary practices—the micro (personal resourcefulness), the meso (distributed activities), and the macro (systems, cultures and contexts) (Figure 2).

A similar framework can be applied to describe expertise for interdisciplinary teaching. That is, expertise for interdisciplinary teaching extends beyond the *teacher's personal expertise* and includes the *teaching expertise* of the entire activity system.

In response to the second consultation question, 'What kind of expertise and resources do teachers need for productive interdisciplinary teaching?' the participants discussed a set of themes across the micro, meso, and macro levels.

At the micro level of teacher personal resourcefulness, the participants emphasised the critical role of *teachers' lived experiences* of practising interdisciplinarity and learning in diverse contexts. They pointed out that interdisciplinarity does not happen 'at a desk'; it needs to be enacted and embodied. Lack of experience makes interdisciplinary learning difficult to imagine and implement. Teachers might not know where to start, how to plan, or how to reflect.

Further, teachers need *confidence and flexibility* when engaging with the uncertainty, ambiguity and 'organised chaos' common in interdisciplinary teaching: 'being comfortable with being uncomfortable' or being 'ok to try and fail' and 'not being afraid of asking for help'.

Similarly, teachers need to be creative problem solvers: finding creative solutions to unexpected issues, being open to trying new things, being creative with 'what you have got', and experiencing 'an aha moment'. Simultaneously, teachers need confidence and flexibility to create relationships, interact and teach with teachers outside their faculty.

Interdisciplinary teaching requires *teachers' personal investment*. Teachers need to understand why they should engage in interdisciplinary practices and change. If teachers have a possibility to pursue their own goals, they are more likely to feel engaged.

Simultaneously, it is vital to recognise *day-to-day pressures* upon teachers, including accountability for subject-specific outcomes, limited time and exhaustion. As the participants noted, teachers often feel 'under the pump' just doing what they need to do to get through a school day. Therefore, it is important to identify and mitigate such pressures, recognise teachers' core functions, and alleviate 'jack of all trade' burdens and non-core functions.

At the meso level of distributed activities, the participants emphasised that *time* for collaboration and physical spaces are also critical. Principals need to be creative in finding ways to give teachers time to co-design curricula and sustain such practices over more extended periods. Spaces where teachers can work together, have 'things on walls', and 'make' and 'move' them are also necessary.

Teachers need to build a *shared 'language repertoire'* that enables them to discuss, debate and design interdisciplinary curricula together. This includes language to learn together, understand pedagogy without getting lost in discussing content, and co-design for learning.

An integral aspect of productive interdisciplinary professional learning and teaching practices is *engagement with experts, mentors, peers and critical friends* that could guide and support planning. For example, teachers supporting each other could help to 'let go of curriculum constraints.' The participants also emphasised the role of 'coherence-makers' who could help teams to navigate curriculum-making conversations and lead them into interdisciplinary thinking.

Interdisciplinary teaching should have a clear *curriculum perspective*: knowing what the learning objective would be and methods for assessing and evaluating it are important. Interdisciplinary curriculum design decisions should be purposeful. For example, how does an assessment task asking students to create a digital story require them to think like a historian? How does it engage with different ways of knowing: 'If we use that activity, what thinking will be activated? What will it afford? What does that structure look like, and what form does it take?'

Teachers need knowledge and skill to use *pedagogical approaches suited for interdisciplinary teaching*, such as project-based learning, including teaching students group work, managing an unstructured classroom with students at different points and working on their own thing, and sustaining focus on curriculum and knowledge.

At the macro level of broader systems, cultures and contexts, the participants emphasised the role of *strong leadership and a strategic approach*. Creating an environment that enables interdisciplinarity is difficult if leadership does not support and champion interdisciplinary culture. A strategic plan, big picture thinking with a clear focus (e.g., social justice, sustainability), a leader who is a risk-taker, and subject leads with a vision are among critical factors.

Strategic, *whole-school approaches* are more likely to be effective and sustainable. For example, the participants pointed out innovative practices that embrace interdisciplinarity at a whole-school scale, such as Big Picture Learning. Simultaneously, they acknowledged that each school and teacher education program is different; taking steps appropriate for the context is more meaningful than making large but unsustainable changes.

Interdisciplinary professional learning plays a vital role, but it should be tailored to the unique needs of each school and situation. They could include small schools in residence, one day a fortnight, mentoring, small professional development sessions, or a layered whole-school approach. Most importantly, interdisciplinary professional learning should resist the deficit views of teachers, support teacher collaboration and build joint teachers' capacity and trust.

Productive interdisciplinary teaching also involves *partnerships with diverse stakeholders* (e.g., parents, industry, community, and councils) in various ways and timeframes. Museums, CSIRO, community members, industry professionals, etc., could contribute necessary resources and expertise. Ongoing engagement could be particularly valuable but not easy to create and sustain. The participants discussed diverse potential models that could support this, such as the 'living libraries' of community experts (with expertise in sustainability, town planning, woodwork, etc.) to tap into.

Access to multimodal resources that can be adapted to specific contexts and *knowledge networks* can also enhance interdisciplinary teaching practices. However, the participants emphasised that the resourcing can only help if a teacher understands the pedagogy. They pointed out that some states have invested in curriculum packages, but the 'magic of a classroom' is in educators. That is, teachers need resources that support their intellectual engagement and the possibility of adapting resources to their teaching needs and context. Ways of helping teachers to feel connected and supported include: professional learning networks (e.g., LinkedIn); opportunities to reach out to colleagues and stay connected with what other people have done (e.g., Teach Meets); and conferences to share resources.

It is particularly critical to *recognise and mitigate systemic barriers and disincentives*. For example, the participants observed that interdisciplinary teaching is not a part of explicit key performance indicators for teachers, teacher education institutions or schools. The NSW system is more prescriptive than some other states, which also works against interdisciplinarity. Teacher shortages, student absenteeism, pressures of day-to-day teaching, and legacy systems also compete for the attention and time of schools, teachers, and teacher educators. While interdisciplinary teaching may actually help to address some of these issues (e.g., through engaging students), drive and support for interdisciplinarity at a system level is needed.

Table 2 summarises the main insights identified from the consultation interviews as they range across the micro, meso, and macro levels.

Table 2: Summary of insights from the consultation interviews about productive interdisciplinary engagement

Micro	Meso	Macro
<ul style="list-style-type: none"> ● Prioritise authentic and supportive teacher interdisciplinary learning experiences. ● Encourage confidence and flexibility, foster creative problem-solving, and openness to try new things. ● Support teachers' personal investment in interdisciplinary teaching. ● Identify and mitigate day-to-day teaching pressures. 	<ul style="list-style-type: none"> ● Make space and time for teachers to design the curriculum together. ● Enable teachers to create a shared language for interdisciplinary learning and co-design. ● Engage with experts, mentors, peers, and critical friends to guide and support planning. ● Adopt a clear curriculum perspective in interdisciplinary teaching. ● Support mastery of interdisciplinary pedagogical approaches (e.g., project-based learning). 	<ul style="list-style-type: none"> ● Prioritise strong leadership and a strategic approach. ● Adopt a whole-school approach, when possible, but value all sustainable steps and initiatives. ● Tailor professional learning according to the unique needs of each school or program. ● Involve diverse stakeholders (e.g., parents, community, council) in various ways and timeframes. ● Enable access to networks and multimodal resources that can be adapted to specific contexts. ● Recognise systemic disincentives and barriers and drive interdisciplinarity at a system level.

Q3: Features of effective professional education for interdisciplinary teaching

Five main themes were salient in the participants' responses to the third consultation question: 'What are the key features of effective professional education for interdisciplinary teaching?'. They were as follows:

- focus on ongoing, practice-based, place-based and systemic interdisciplinary professional learning;
- support teachers' immersive and embodied interdisciplinary learning experiences;
- create opportunities to observe and discuss diverse teaching practices;
- build safe spaces with permission to create, collaborate and play; and
- support organic and socially-oriented professional learning

Effective interdisciplinary learning is ongoing, practice-based, place-based and systemic. The participants observed that interdisciplinary professional learning cannot be one-off and requires a career-long approach. There is nothing simple about interdisciplinarity; initial knowledge base and skills are important. Initial teacher education courses could help pre-service teachers gain a foundational understanding and experience of interdisciplinary teaching and learning. However, interdisciplinary teaching requires an understanding of how schools work, and, thus, it could be hard to embrace such teaching practices in early career stages. Therefore, there is a need for follow-up professional learning. In an in-service context, interdisciplinary professional learning works best when aligned with the school's vision and long-term commitments. For example, the participants mentioned that professional learning is likely to be more successful when it is part of a strategic plan and involves working for a whole year, as opposed to one-off professional learning. Further, there is a need for flexible learning options, such as mentorship and coaching. Such professional learning supports teachers' autonomy, relevance and alignment with where teachers are and what they hope, and want, to achieve.

Effective teachers' interdisciplinary learning is experiential, immersive, active and embodied. The participants noted that learning to teach without engaging in teaching does not work: sometimes, teachers understand what it is but do not know how to apply it and enact it as a teacher. By doing it themselves, teachers can see the value and gain essential experience.

Further, observations of teaching practices and discussions are at the core of quality teaching. The participants mentioned that learning with teachers from outside their teaching area is particularly rich, because, by observing each other's lessons, teachers are much more likely to experience and understand the links. Among the key conditions are opportunities to get outside their insular teaching spaces and build their shared understanding and language of what it means to teach well.

Overall, interdisciplinary learning is dialogical, interpersonal, and experiential; and effective professional learning happens in safe, collaborative spaces that give teachers permission to create, experiment, and play. Interdisciplinary professional learning can be challenging but engaging. The participants observed that play is a great opportunity to imagine different ideas. They described such learning as a 'freedom to prototype', 'freedom to try things and what works and didn't work', 'fail fast to succeed faster', and 'fun, creative time together'.

While many participants focused on formal professional learning options, some participants emphasised the value of organic, grassroots, socially-oriented professional learning initiatives, such as: *online communities* sharing resources and successes as examples and inspiration for others; *teach meets* involving open, informal, low-stakes, dynamic professional conversations hosted in different locations; and *hackathons* offering low-stakes, inclusive and fun professional learning environments and enabling participants to become inspired, learn new ideas and make connections.

Q4: Barriers and enablers for developing expertise for interdisciplinary teaching⁵

A range of interrelated barriers and enablers related to developing pre- and in-service teachers' expertise for interdisciplinary teaching were identified from the consultation interviews. They included six main barriers:

- assumptions, motivation, and capabilities;
- constraining stakeholder beliefs and practices;
- complexity of practical arrangements;
- curriculum and assessment pressures;
- schools' differential access to resources; and
- workforce and organisational tensions.

These barriers were both personal and environmental.

Teachers' and teacher educators' assumptions, motivation, and capabilities were the main barriers at the personal level. The participants noted that lack of pre-service and in-service teachers' motivation and agency could limit their engagement in learning for interdisciplinary teaching. Similarly, insufficient teacher educators' knowledge, skills, confidence or motivation to prepare teachers for interdisciplinary teaching—such as seeing interdisciplinary connections as an add-on to discipline-focused teacher education—could be a significant obstacle. During the consultation interviews, the participants also mentioned that narrow assumptions about interdisciplinarity, a teacher's role, and schooling could be limiting factors.

Various stakeholders in and around teacher education, such as school and university leaders, external partners, parents, and students, may implicitly—or explicitly—inhibit teachers' interdisciplinary learning activities. For example, some parents may see interdisciplinary learning as wasting time.

In terms of organisational barriers, the participants mentioned critical constraints relating to the complexity of practical arrangements, such as: the time needed for teacher educators and academics to develop high-quality courses for interdisciplinary teaching; practical constraints about embedding interdisciplinarity into disciplinary pre-service teacher education structures; lack of funds, time, or space for interdisciplinary professional learning; and challenges associated with establishing sustainable partnerships and continuous professional learning.

During the consultation interviews, the participants shared their views about how existing curriculum constraints often impose boundaries around specific subjects, not only in schools but also in teacher education programs. This ignores the underlying connections between disciplines and limits the space and time available to engage with interdisciplinary practices. Current assessment regimes, focused on disciplinary outcomes, could also inhibit teachers' willingness to engage with interdisciplinary teaching practices and professional learning.

⁵ A version of this section was published as Swist, T., Markauskaite, L., Goodyear, P., Wrigley, C. & Mosely, G. (2023a) Why you need to spot the invisible elephant. *EduResearch Matters*, 27 April 2023 <https://blog.aare.edu.au/why-you-need-to-spot-the-invisible-elephant>

Schools' differential access to funding and resources also makes sustaining whole-school interdisciplinary approaches challenging. For example, not all schools can afford mentors, find time and space to work as an interdisciplinary team, or access suitable learning spaces for group work, project-based, or embodied learning.

Furthermore, some participants highlighted workforce and organisational tensions and barriers, such as the increasing administrative burdens that teachers and teacher educators face, linked to an intensified compliance and reporting culture, plus the realities of systemic pressures relating to teacher recruitment and retention.

In contrast, the main enablers were as follows:

- teacher expertise, autonomy and dispositions;
- formal and informal learning, collaboration, and communication opportunities;
- permission to play and be creative as part of the curriculum-making process;
- resourcing flexible and 'hands-on' pedagogical approaches; and
- an ecosystem that supports, showcases, and shares successful interdisciplinary practices.

Teachers' attributes identified as key enablers were related to their expertise, autonomy, and dispositions, such as flexibility, confidence, persistence, creativity, problem-solving, and willingness to engage with uncertainty. The participants also reiterated the need to value educator professionalism while recognising the day-to-day pressures that may inhibit and constrain interdisciplinary work.

Many other enabling factors were closely related to the earlier described features of effective professional learning, such as opportunities for formal and informal learning, collaboration, communication, and resourcing flexible and 'hands-on' pedagogical approaches. The participants indicated an array of useful resources and websites that could be readily utilised for different interdisciplinary projects in schools and teacher education (e.g., sustainability, astronomy). However, teachers need permission to play and be creative in curriculum-making.

The participants also highlighted the critical role of the overall institutional ecosystem that showcases, supports, and shares successful interdisciplinary practices. This includes teachers who have disciplinary expertise and a disposition to engage in interdisciplinarity, leadership that has high expectations and champions interdisciplinary teaching, supportive stakeholders, including parents and local communities, and space to explore, design and teach interdisciplinary lessons.

Overall, most participants mentioned multiple interconnected barriers and enablers, suggesting that successful development of interdisciplinary expertise relies not so much on individual factors, but on the overall ecosystem.

Synthesis and implications for pre-service and in-service education

The consultation interviews have revealed that, in the context of teacher education, interdisciplinarity is primarily understood as a set of teachers' dispositions to engage in high-quality, purposeful integrative teaching practices. Such practices connect disciplinary teaching across curricula, involve working with multiple people and across contexts, and address challenging contemporary problems.

The most critical areas of teachers' professional practices and needs do not relate to particular topics (e.g., sustainability or STEM [science, technology, engineering and mathematics]) but involve a set of general interdisciplinary curriculum-making, teaching and collective professional learning practices, such as identifying 'launchpads' to branch out, developing (inter)disciplinary fluency, and using pedagogical approaches that support breaking down subject boundaries.

Further, interdisciplinary teaching is multifaceted. It is not limited to the micro level of teachers' personal resourcefulness. It spans all levels of educational ecosystems, including collaborative (meso level) and environmental (macro level) aspects.

Effective teacher professional education is primarily characterised as *ongoing* and *embedded* in collective practices, contexts and visions of learning. It includes individual and collective, formal and informal learning.

The main barriers and enablers for developing teachers' interdisciplinary expertise are *personal*, related to teachers' resourcefulness, and *environmental*, related to other actors, organisational factors, systems, culture and structures.

These outcomes suggest that developing interdisciplinary expertise requires holistic ecological approaches. However, addressing all aspects simultaneously is an impossible task. Teacher educators and school leaders primarily need resources and tools that would allow them to understand and navigate the space of interdisciplinary practices, establish possibilities and priorities, and create professional learning opportunities purposefully and systematically. These initial outcomes—mapping how interdisciplinarity is understood, what teachers do, what capabilities they need, what opportunities they have and what barriers they face—could be a starting point for creating effective interdisciplinary professional learning (see Summary in Appendix 2).

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Appendices

Appendix 1. Project overview

<i>Phase</i>	<i>Aim</i>	<i>Method</i>	<i>Outputs and knowledge translation insights</i>
<p>Phase 1</p> <p><i>Late 2021– Late 2023</i></p> <p><i>Consultation and scoping study and initial development of teacher interdisciplinary expertise framework</i></p>	<p>To develop an initial consultation paper on the nature of interdisciplinary expertise and how it is learnt.</p>	<p>Desktop review and feedback from the project reference group</p>	<p>Consultation paper (Markauskaite et al., 2023) and guiding questions to inform consultation interviews, a webinar, and a workshop:</p> <ul style="list-style-type: none"> • What are the most important areas of teachers' interdisciplinary practices and needs for professional learning? • What kind of expertise and resources do teachers need for productive interdisciplinary teaching? • What are the key features of effective professional education for interdisciplinary teaching? • What are the main barriers and enablers for developing pre- and in-service teachers' expertise for interdisciplinary teaching?
	<p>To conduct a scoping literature review on the development of teacher interdisciplinary expertise to identify current models, key elements of effective practice, evidence, as well as gaps in the literature.</p>	<p>Scoping review</p>	<p>Two scoping reviews:</p> <ul style="list-style-type: none"> • Understanding pre-service and in-service teachers' expertise for interdisciplinary teaching practices: A scoping review (Mosely et al., submitted). • Curricular design patterns and possibilities: A configurative literature review to enact an interdisciplinary education pattern language (Swist et al., submitted).
	<p>To identify current areas of teacher interdisciplinary practices and challenges, as well as practices and barriers in developing pre- and in-service teachers' interdisciplinary expertise, and to translate these ideas to Australian and NSW school contexts.</p>	<p>Interview-consultations with 23 experts and stakeholders</p> <hr/> <p>First webinar with approximately 30 participants</p>	<p>Multistakeholder perspectives to inform first workshop (aligned with framework questions). E.g., emerging dispositions identified for interdisciplinary teaching. I.e. disposition to be:</p> <ul style="list-style-type: none"> • transformative: moving beyond subject siloes and disciplinary bunkers; • adaptive: linking and tailoring the curriculum for specific contexts; • relational: negotiating uncertainty, interests, and needs with diverse stakeholders; • purposeful: guiding pedagogical support and accountability; • action-oriented: learning-through-doing. <p>This report</p>

Phase	Aim	Method	Outputs and knowledge translation insights
	To design and conduct a model-building workshop to create an initial framework for the development of teacher interdisciplinary expertise.	First workshop with 10 participants	Design activities: 1: Constructing a space for bringing knowledge: 2: Laying the groundwork and creating frameworks: 3: Laying the groundwork to creating framework for interdisciplinary teacher expertise.
Phase 2: Late 2023 – Mid 2024	To develop a framework to help participants embed interdisciplinary expertise development in their teacher education programs for preservice and in-service teachers (and inform resource co-creation).	Phase 1 synthesis and feedback from 5 project reference group members	An initial ecological framework of teachers' interdisciplinary expertise (Swist et al., 2023b, 2023c). Includes interdisciplinary levels (micro, meso, macro), aspects of teachers' interdisciplinary expertise, research-practice insights, plus Explore, Share and Build activities. This framework will inform second webinar and workshop
<i>Development and testing of design resources in pre-service teacher education and in-service professional development</i>		Second webinar with approximately 15 participants	Multistakeholder perspectives to inform the refinement of the framework and second design workshop.
	To conduct a design workshop for pre-and in-service educators	Second workshop with 8 participants	Development of five cases and ideas for design principles.
	To develop and test a set of specific design patterns. This phase will build on participatory innovation co-design and patterns-based approach.	Follow-up co-design	Design principles for teacher educators (Mosely et al., 2024). A resource with 12 design principles and 5 cases for teacher educators for assisting to embed interdisciplinary expertise development in their teacher education programs.
Engagement and dissemination	Reaching most important stakeholders and participants who can benefit the most	Consultations, webinars, design workshops, reports, publications	Continuous

Appendix 2. Insights from consultation interviews: A summary

Dispositions for interdisciplinarity (Background Question)	
<p>DISPOSITION TO CONNECT SUBJECTS—moving beyond disciplinary bunkers. E.g., building an integrated understanding of a phenomenon.</p> <p>DISPOSITION TO BE TRANSFORMATIVE—being fearless and resilient. E.g., having courage to try new things.</p> <p>DISPOSITION TO BE FAITHFUL TO KNOWLEDGE—engaging with knowledge deeply. E.g., understanding knowledge and ways of knowing.</p> <p>DISPOSITION TO BE ADAPTIVE—tailoring the curriculum for specific contexts. E.g., being flexible and engaging in curriculum-making.</p> <p>DISPOSITION TO BE RELATIONAL—collaborating with diverse stakeholders. E.g., engaging with ambiguity and negotiating.</p> <p>DISPOSITION TO BE ACTION-ORIENTED—learning through doing. E.g., focusing on real-world issues.</p> <p>DISPOSITION TO BE PURPOSEFUL—supporting students understanding. E.g., creating a scaffolded environment for interdisciplinary learning.</p>	
Barriers and enablers for developing expertise for interdisciplinary teaching (Question 4)	
<p>Barriers</p> <ul style="list-style-type: none"> ● Assumptions, motivation, and capabilities ● Constraining stakeholder beliefs and practices ● Complexity of practical arrangements ● Curriculum and assessment pressures ● Schools' differential access to resources ● Workforce and organisational tensions 	<p>Enablers</p> <ul style="list-style-type: none"> ● Teacher expertise, autonomy and dispositions ● Formal and informal learning, collaboration, and communication opportunities ● Permission to play and be creative as part of the curriculum-making process ● Resourcing flexible and 'hands-on' pedagogical approaches ● An ecosystem that supports, showcases, and shares successful interdisciplinary practices

Expertise and resources for productive interdisciplinary teaching (Question 2)		
<p>Micro</p> <ul style="list-style-type: none"> ● Prioritise authentic and supportive teacher interdisciplinary learning experiences. ● Encourage confidence and flexibility, foster creative problem-solving, and openness to try new things. ● Support teachers' personal investment in interdisciplinary teaching. ● Identify and mitigate day-to-day teaching pressures. 	<p>Meso</p> <ul style="list-style-type: none"> ● Make space and time for teachers to design curricula together. ● Enable teachers to create a shared language for interdisciplinary learning and co-design. ● Engage with experts, mentors, peers, and critical friends to guide and support planning. ● Adopt a clear curriculum perspective in interdisciplinary teaching. ● Support mastery of interdisciplinary pedagogical approaches (e.g., project-based learning). 	<p>Macro</p> <ul style="list-style-type: none"> ● Prioritise strong leadership and a strategic approach. ● Adopt a whole-school approach, when possible, but value all sustainable steps and initiatives. ● Tailor professional learning according to the unique needs of each school or program. ● Involve diverse stakeholders (e.g., parents, community, council) in various ways and timeframes. ● Enable access to networks and multimodal resources which can be adapted to specific contexts. ● Recognise systemic disincentives and barriers, and drive interdisciplinarity at a system level.
Main considerations for pre-service and in-service education		
<p>Areas of teachers' interdisciplinary practices and needs (Question 1)</p> <ul style="list-style-type: none"> ● Identifying 'launchpads' to branch out when engaging in interdisciplinary teaching ● Developing (inter)disciplinary fluency and addressing assumptions, biases, habits and fears ● Utilising pedagogical approaches that support breaking down subject boundaries ● Engaging with and shaping the curriculum in creative ways ● Tailoring to pre- and in-service education needs and targeting workforce issues ● Collective capacity-building, learning and safety 	<p>Features of effective professional education (Question 3)</p> <ul style="list-style-type: none"> ● Focus on ongoing, practice-based, place-based and systemic interdisciplinary professional learning ● Support teachers' immersive and embodied interdisciplinary learning experiences ● Create opportunities to observe and discuss diverse teaching practices ● Build safe spaces with permission to create, collaborate, and play ● Support organic and socially oriented professional learning 	