Developing teachers' interdisciplinary expertise

Consultation report

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Acknowledgement of Country
We acknowledge the tradition of custodianship and law of the Country on which the University of Sydney and the University of Queensland campuses stand. We pay our respects to those who have cared and continue to care for Country.

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Summary

This report is a part of the project 'Developing teachers' interdisciplinary expertise', funded by a NSW Department of Education Strategic Leveraging grant. The 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.

This report presents key insights from consultation interviews conducted to inform the co-design of resources for teacher educators when developing teachers' interdisciplinary expertise. The consultation interviews involved 23 participants with relevant expertise and experience: teacher educators, leaders and teachers from governmental and non-governmental NSW schools, student teachers, Department of Education representatives, and professional learning providers.

The consultation interviews 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) 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.

Introduction

This report is a part of the project 'Developing teachers' interdisciplinary expertise', funded by the 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.

This report is a part of the first phase of the project. It presents key insights from the consultation interviews, which will inform further translational process and co-design of resources for teacher educators for developing teachers' interdisciplinary expertise (see Project overview in Appendix 1).

Consultation interviews

In the first project phase, we 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., 2023). 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. The main insights from these interviews are summarised in this report. These insights will be used to inform the development of an overarching framework that articulates the main aspects of teachers' interdisciplinary expertise and to co-create design resources for embedding the development of teachers' interdisciplinary expertise in pre-service teacher education and in-service professional development. A glossary of the main terms used in this report can be found in Appendix 2.

For more information

Visit the project website: https://interdisciplinaryexpertise.org/developing-teachers-interdisciplinary-expertise

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Methodology

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 1). 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.
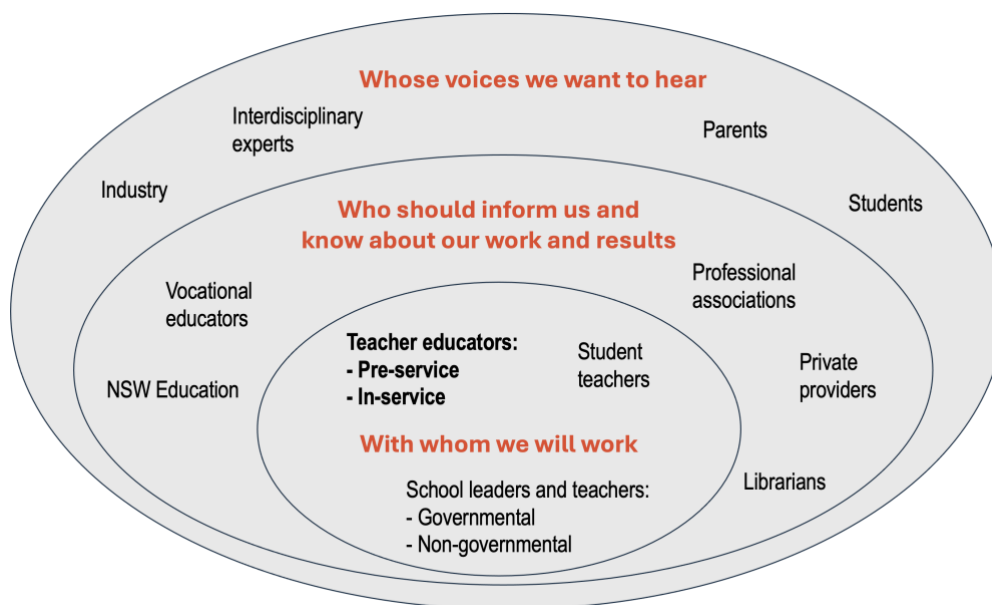
Figure 1: Project informant and stakeholder map

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 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., 2023), 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-recoded and detailed notes were taken.

Box 1: 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 2). The main findings are presented in the next section and summarised in Appendix 3. The quotes are based on the researchers' notes; they aim to convey the gist and are not verbatim.

QUESTION 1

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

QUESTION 2

What kind of expertise and resources do teachers need for productive interdisciplinary teaching?

BACKGROUND QUESTION
Perspectives on interdisciplinarity

QUESTION 3

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

QUESTION 4

What are the main barriers and enablers for developing expertise for interdisciplinary teaching in pre- and in-service teachers' education?
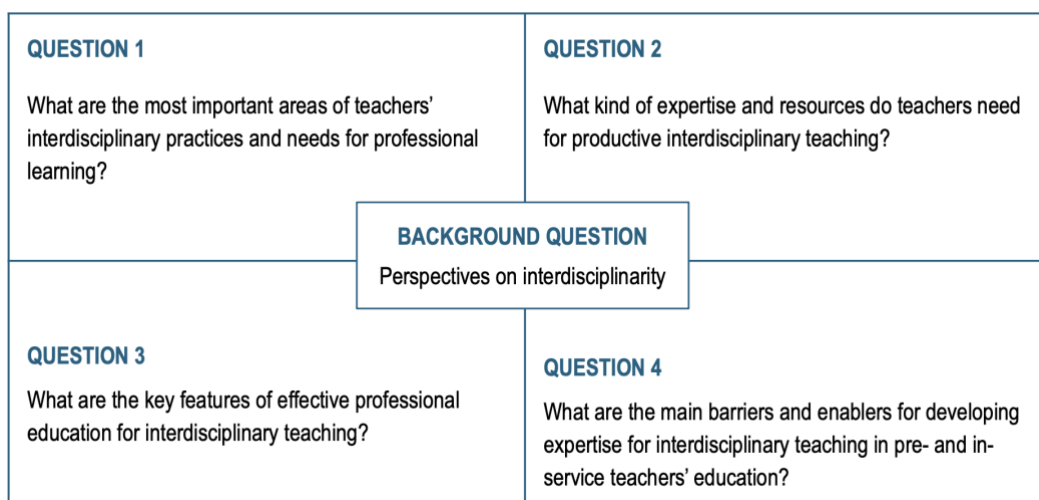
Figure 2: Framework for synthesising findings

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 3 summarises the main interdisciplinary dispositions emerging from the interviews.

DISPOSITION TO BE TRANSFORMATIVE –
being fearless and resilient

Having the courage to try new things

DISPOSITION TO BE FAITHFUL TO KNOWLEDGE –
engaging with knowledge deeply

Understanding knowledge and ways of knowing

DISPOSITION TO CONNECT SUBJECTS –
moving beyond disciplinary bunkers

Building an integrated understanding

DISPOSITION TO BE ADAPTIVE –
tailoring the curriculum for contexts

Being flexible and engaging in curriculum-making

DISPOSITIONS FOR INTERDISCIPLINARITY

DISPOSITION TO BE PURPOSEFUL –
supporting students' understanding

Creating a scaffolded environment for interdisciplinary learning

DISPOSITION TO BE RELATIONAL –
collaborating with diverse stakeholders

Engaging with ambiguity and negotiating

DISPOSITION TO BE ACTION-ORIENTED –
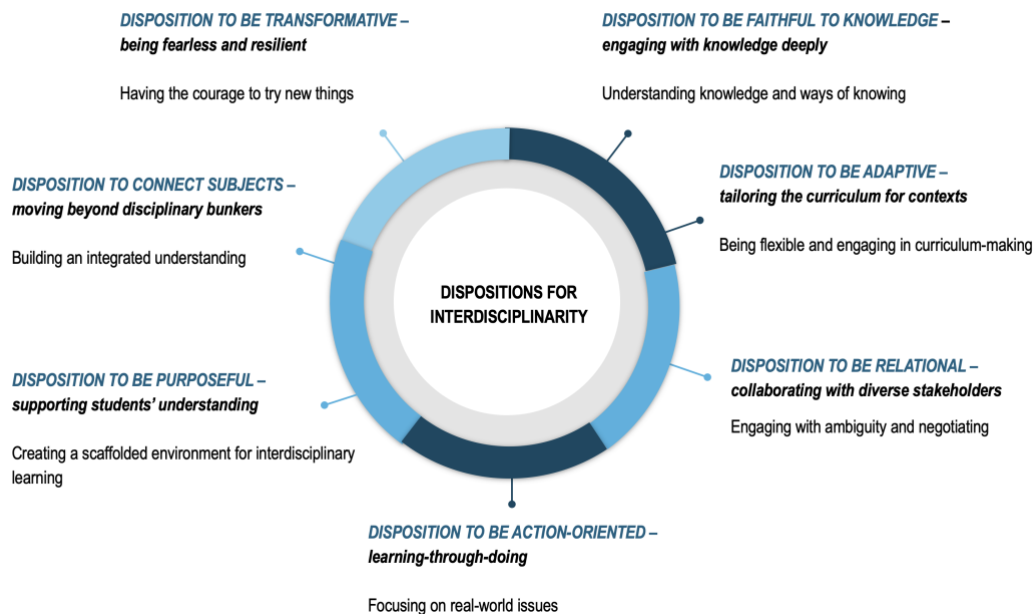*learning-through-doing*

Focusing on real-world issues

Figure 3: 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., 2023). 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 4).

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.
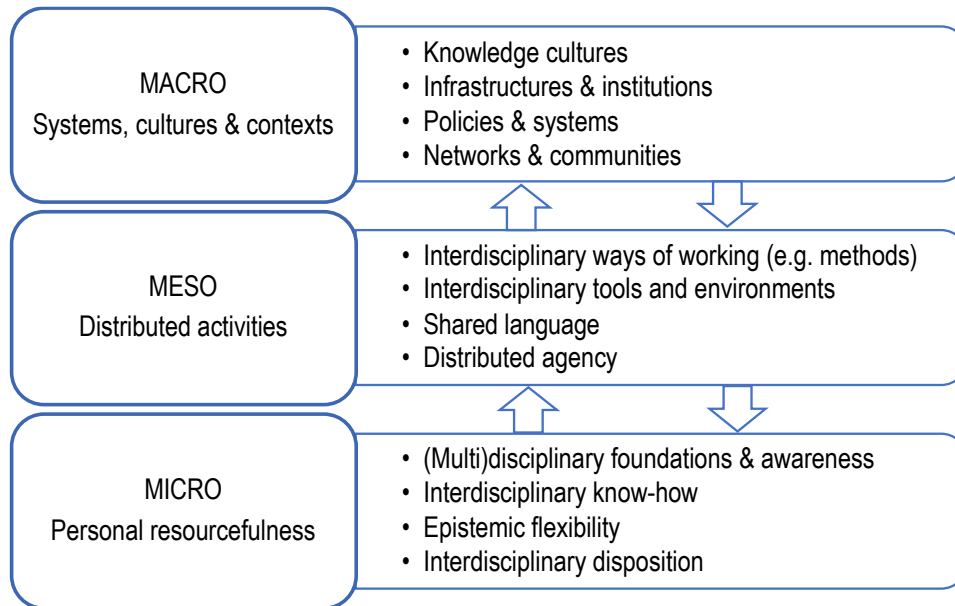

MACRO
Systems, cultures & contexts
- Knowledge cultures
- Infrastructures & institutions
- Policies & systems
- Networks & communities

MESO
Distributed activities
- Interdisciplinary ways of working (e.g. methods)
- Interdisciplinary tools and environments
- Shared language
- Distributed agency

MICRO
Personal resourcefulness
- (Multi)disciplinary foundations & awareness
- Interdisciplinary know-how
- Epistemic flexibility
- Interdisciplinary disposition

Figure 4: An ecological framework of interdisciplinary practices and expertise (after Markauskaite et al., 2023)

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

Table 1: Summary of insights from the consultation interviews about productive interdisciplinary engagement

Micro	Meso	Macro
• 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.	• 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).	• 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 teaching[1]

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.

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[1] A version of this section was published as Swift, T., Markauskaite, L., Goodyear, P., Wrigley, C. & Mosely, G. (2023) 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

Phase	Aim	Method	Outputs and knowledge translation insights
Phase 1 *Late 2021– Late 2023* *Consultation and scoping study and initial development of teacher interdisciplinary expertise framework*	To develop an initial consultation paper on the nature of interdisciplinary expertise and how it is learnt.	Desktop review and feedback from the project reference group	Consultation paper (Markauskaite et al., 2023) and guiding questions to inform consultation interviews, a webinar, and a workshop: ● 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?
	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.	Scoping review	Two scoping reviews: ● 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).
	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.	Interview-consultations with 23 experts and stakeholders	Multistakeholder perspectives will inform the first workshop (aligned with the consultation questions).
		First webinar with approximately 30 participants	● See this report
	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	Forthcoming

Phase	Aim	Method	Outputs and knowledge translation insights
Phase 2: *Late 2023 – Mid 2024* *Development and testing of design resources in pre-service teacher education and in-service professional development*	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	Forthcoming
		Webinar 2: scheduled for 12 December 2024	Forthcoming
	To conduct a design workshop for pre-and in-service educators	Workshop 2: scheduled for early 2024	Forthcoming
	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: scheduled for early-mid 2024	Forthcoming
Engagement and dissemination	Reaching most important stakeholders and participants who can benefit the most	Consultations, webinars, design workshops, reports, publications	Ongoing

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Appendix 2. Glossary of terms

- *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).

- *Teaching expertise:* the capacity to perform productively, knowledgeably, and skilfully in relation to the encountered situation and context. It includes the relationship between teacher's personal attributes (knowledge, skills, dispositions, etc.) and a broader teaching activity system (shared goals, cultural, social, material and knowledge resources, other people, etc.). Accordingly, *interdisciplinary expertise* refers to the capacity for productive, knowledgeable, and skilful engagement in those kinds of professional practices that involve several disciplines or other knowledge fields and foster connections between them.

- *Teachers' interdisciplinary expertise* and *teaching interdisciplinary expertise* are used synonymously. They refer to the relationship between the teacher's attributes and their teaching activity (which is situated in a larger system).

- *Competence, skills and capability* are common terms used in 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.

Appendix 3. Insights from consultation interviews: A summary

Dispositions for interdisciplinarity (Background Question)
DISPOSITION TO CONNECT SUBJECTS—moving beyond disciplinary bunkers. E.g., building an integrated understanding of a phenomenon.   DISPOSITION TO BE TRANSFORMATIVE—being fearless and resilient. E.g., having courage to try new things.   DISPOSITION TO BE FAITHFUL TO KNOWLEDGE—engaging with knowledge deeply. E.g., understanding knowledge and ways of knowing.   DISPOSITION TO BE ADAPTIVE—tailoring the curriculum for specific contexts. E.g., being flexible and engaging in curriculum-making.   DISPOSITION TO BE RELATIONAL—collaborating with diverse stakeholders. E.g., engaging with ambiguity and negotiating.   DISPOSITION TO BE ACTION-ORIENTED—learning through doing. E.g., focusing on real-world issues.   DISPOSITION TO BE PURPOSEFUL—supporting students understanding. E.g., creating a scaffolded environment for interdisciplinary learning.

Barriers and enablers for developing expertise for interdisciplinary teaching (Question 4)	
Barriers	**Enablers**
• 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	• 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)		
Micro ● 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.	**Meso** ● 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).	**Macro** ● 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		
Areas of teachers' interdisciplinary practices and needs (Question 1) ● 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	**Features of effective professional education (Question 3)** ● 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	