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ORIGINAL ARTICLE

Learning from Lessons: studying the structure and construction of mathematics teacher knowledge in Australia, China and Germany

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Abstract The major premise of this project is that teachers learn from the act of teaching a lesson. Rather than asking "What must a teacher already know in order to practice effectively?", this project asks "What might a teacher learn through their activities in the classroom and how might this learning be optimised?" In this project, controlled conditions are created utilising purposefully designed and trialled lesson plans to investigate the process of teacher knowledge construction, with teacher selective attention proposed as a key mediating variable. In order to investigate teacher learning through classroom practice, the project addresses the following questions: To what classroom objects, actions and events do teachers attend and with what consequence for their learning? Do teachers in different countries attend to different classroom events and consequently derive different learning benefits from teaching a lesson? This international project combines focused case studies with an online survey of mathematics teachers' selective attention and consequent learning in Australia, China and Germany. Data include the teacher's adaptation of a pre-designed lesson, the teacher's actions during the lesson, the teacher's reflective thoughts about the lesson and, most importantly, the

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consequences for the planning and delivery of a second lesson. The combination of fine-grained, culturally situated case studies and large-scale online survey provides mutually informing benefits from each research approach. The research design, so constituted, offers the means to a new and scalable vision of teacher learning and its promotion.

Keywords Teacher learning · Teacher attention · Teacher knowledge · Mixed methods · International comparison · Mathematics lessons

Introduction

The improvement of teaching quality has been a focus of policy reforms in Australia and overseas (AITSL 2011; COAG 2009; OECD 2014b). Quality teaching in a rapidly changing society demands that teachers continue to develop professionally (Darling-Hammond 1998). The literature on teacher learning is dominated by the assumption that this learning must occur through organised programs of teacher professional development (e.g. Bell, Wilson, Higgins and McCoach 2010). This is a consequence of the understandable emphasis accorded to what a teacher already knows that equips them to teach well (Ball, Thames and Phelps 2008). Even the report of the OECD's Teaching and Learning International Survey (TALIS) (OECD 2014b) suggested by omission that teacher learning requires some type of formal professional development program, since the survey gave no recognition to other modes of learning by teachers. Our project inverts that relationship by identifying productive teacher learning as a consequence and, indeed, a constitutive component of good teaching practice.

We suggest that it is understanding the teacher learning process that should lead to improvement in both teacher knowledge and practice. We propose teacher selective attention as a key mediating variable determining the teacher's capacity to utilise the learning potential of classroom events and situations. If, as we surmise, major opportunities for teacher learning arise through the daily experience of teaching lessons, then a better understanding of how this learning occurs should provide a key to enhanced teacher learning (and therefore teacher performance) on a much larger scale than could ever be accomplished through professional development courses. What we learn from this research should optimise teachers' capacity to learn from their everyday practice. Our long-term goal is to facilitate the evidence-based optimisation of teacher learning during the design and teaching of lessons in a scalable and sustainable way.

The pilot study and the current project

In 2014 and 2015, a pilot study was conducted which informed the research design of this project. The aim of the pilot study was to investigate what teachers learn from the act of teaching a lesson and the planning of a subsequent lesson. A key element in the research design of the pilot study was the provision of lesson plans for purposefully designed experimental mathematics lessons (D. M. Clarke and Roche 2014), and these provided the initial context for this investigation of teacher selective attention, reflection and learning. Three middle school teachers (grades 5, 6 and 7) in Melbourne, Australia; one grade 5 teacher in Lisbon, Portugal; and one grade 7 teacher in Chicago,

USA, were involved in the pilot study. They were first asked to adapt a researcher-designed lesson plan and deliver the lesson to their usual class. The teachers were then asked to design a follow-up lesson themselves and deliver the lesson to the same class a few days after the first lesson. Pre- and post-lesson interviews were conducted with each of the teachers for the first and the follow-up lessons, respectively. Teachers were given a written test of content knowledge and pedagogical content knowledge and a beliefs survey adapted from the instruments developed for the 17-country teacher education and development study in mathematics (TEDS-M) (Tatto et al. 2012).

The pilot study successfully demonstrated the viability of the research design in generating evidence of teacher selective attention and teacher knowledge construction. Focusing on analysing the teacher pre- and post-lesson interview transcripts, the pilot study identified similarities and differences in the kinds of lesson elements and events that the teachers paid attention to pre- and post-lesson. Analysis also suggested that the lesson topic (e.g. decimals or estimation of mass) may influence teacher attention and therefore the knowledge construction process. As each teacher in the pilot only taught one pair of lessons, we hope to identify how different lessons afford different learning for the same teacher and how teaching a lesson based on the same initial lesson plan might afford different learning opportunities for different teachers. The potential influence of the lesson topic on teacher selective attention and consequent learning will be addressed in the current project design. The effective implementation of the pilot study in multiple countries (Australia, the USA and Portugal) also confirmed the utility of the research design for cross-cultural comparisons. Findings from the pilot study can be found in D. M. Clarke, Clarke, Roche and Chan (2015) and Roche, Clarke, Clarke and Chan (2016).

This project builds on and extends the pilot study to involve multiple case studies and an online survey to study mathematics teachers' selective attention and consequent learning in Australia, China and Germany. The project will generate and analyse data on the teacher's adaptation of a pre-designed lesson, the teacher's actions during the lesson, the teacher's reflective thoughts about the lesson and, most importantly, the consequences for the planning and teaching of a second lesson. The project will use a classification system already developed from the pilot study to identify and analyse teacher selective attention and teacher learning. By creating conditions conducive to the visible enactment of teacher learning in classrooms, this project seeks to better understand teacher learning as process and as product and to identify the means by which it might be more effectively promoted. This methodological combination addresses the urgent need for new understanding of teacher in-class learning and new insights into how teacher opportunities to learn might be expanded in cost-effective ways.

In order to understand teacher in situ learning and thereby better equip teachers to continually develop as professionals, the project addresses these key research questions (RQs):

RQ1 To what classroom objects, actions and events do teachers attend and with what consequence for their learning?
RQ2 How is teacher selective attention influenced by existing teacher knowledge and beliefs?
RQ3 How is teacher selective attention influenced by the lesson's content and structure?

RQ4 How is teacher selective attention influenced by contextual characteristics of school and classroom?

RQ5 Do teachers in different countries/cultures attend to different classroom events and consequently derive different learning benefits from teaching a lesson?

This project investigates teacher learning as situated practice, in curricular, organisational and cultural terms. The five research questions address, in a very structured and strategic way, the knowledge needed if teacher in-class learning (and thereby teacher quality) is to be advanced. International comparison increases the study's capacity to identify the objects of teacher selective attention and the different learning consequences. The combination of Australia, China and Germany is constructed to provide insight through similarity and contrast in student achievement (OECD 2014a), in teacher professionalism and expertise (Tatto et al. 2012), and in the cultural background of the school communities (Thomson, De Bortoli and Buckley 2013).

What is state of the art and what contribution will we make?

Consistent with Shulman (1987), we contend that teachers engage in significant learning through their daily practice, and that this offers the most fruitful opportunity for the investigation and large-scale advancement of teacher knowledge and improved practice.

Our research design takes two premises as central:

(i) When teaching a lesson, teachers learn from those things to which they attend; and
(ii) The objects of a teacher's attention when teaching a lesson and the significance accorded to those objects (their salience) are determined by the teacher's existing knowledge and beliefs, the nature and goals of the lesson, and the context in which the lesson occurs (see Fig. 1).

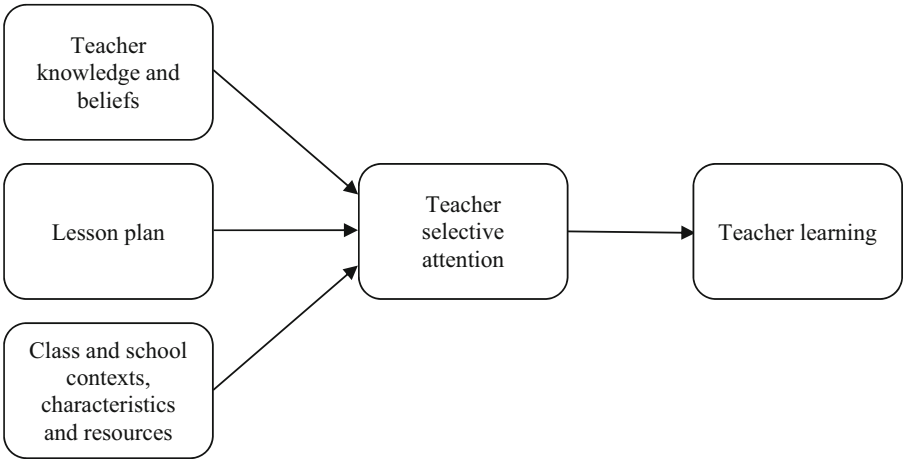

Fig. 1 Conceptual framework

We contend that both of these propositions are plausible and consistent with contemporary learning theory and research (e.g. Gibson 1986; Kolb 1984; Marton and Booth 1997; Sweller, Ayres and Kalyuga 2011).

Research specifically into teacher in-class learning is a relative silence in the literature. Margolinas, Coulange and Bessot (2005) and Leikin and Zazkis (2010) are exceptions, yet their focus is on what is learned, rather than how this occurs. This project addresses the challenge of making the process of teacher in situ learning visible.

The conceptual framework of this project builds on the non-linear "interconnected model of teacher professional growth" (D. J. Clarke and Hollingsworth 2002; see Fig. 2), which has been widely employed, particularly in mathematics and science teacher education (see e.g. Justi and van Driel 2006; Witterholt, Goedhart, Suhre and van Streun 2012). The model is an elaboration of the earlier Clarke-Peter model of professional growth (D. J. Clarke and Peter 1993; Peter 1996). The 2002 model proposes "enactment" and "reflection" as essential mechanisms for the occurrence of teacher learning and identifies "salient outcomes" as a key determinant of teacher learning.

Since the publication of the interconnected model, a substantial literature has sprung up around "teacher noticing", significantly informed by Mason's (2002) book, particularly in mathematics education but also in science education (e.g. Choppin 2011; Mitchell and Marin 2015; Van Es and Sherin 2002). However, the object/s of teacher noticing are frequently restricted to "students' mathematical thinking" (Fernández, Llinares and Valls 2013), "students' multiple mathematical knowledge bases" (Roth McDuffie et al. 2014) and "children's early numeracy" (Schack et al. 2013). Like the earlier work of Guskey (1986), this emphasis on student outcomes under-represents the range of classroom events and outcomes that teachers consider salient to the effective functioning of the classroom (D. J. Clarke and Hollingsworth 2002).

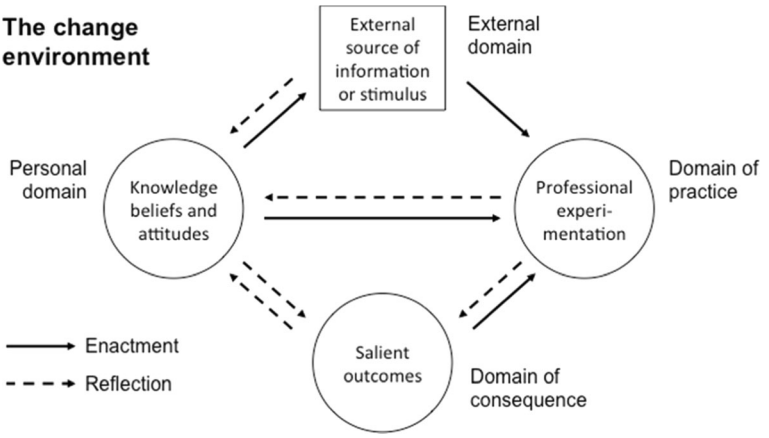

Fig. 2 The interconnected model of teacher growth (image reproduced from D. J. Clarke and Hollingsworth (2002))

Schoenfeld (2008) usefully acknowledged teacher capacity to hold in mind multiple, parallel goals and match the relative prioritisation of these to the needs of the situation. The long-term aim of our project is to assist teachers in broadening their conception of what might be attended to in class and thereby broaden what might be learned. In particular, we expect international comparisons to reveal a breadth of possibilities for attention and learning not currently recognised in the separate local teaching communities (Fernández, Cannon and Chokshi 2003).

Simon (2007) focused attention on teachers' capacity to learn from their teaching and questioned the efficacy of "teachers' assimilatory schemes". His work rightly distinguished what was perceived from what was inferred. Taking "salient outcomes" as our conceptual point of entry in the development of a model of teacher in situ learning, we propose "teacher selective attention" as a critical determinant of teacher learning (see Fig. 1). The focus on "teacher selective attention" emphasises the purposeful nature of teacher attention, where the identification of the targets of the teacher's selective attention makes visible the teacher's judgments of salience (D. J. Clarke and Hollingsworth 2002). Our research design creates conditions conducive to the enactment of teacher inference and the learning arising from their selective attention. In this study, the teacher demonstrates through lesson design and teaching their prioritisation of the objects available for their attention, rather than simply recounting them.

Previous research on classroom discourse (D. J. Clarke 2013) demonstrated the value of studying social phenomena in contrasting social settings. By constructing the study as an international comparison, we address the possibility that teacher attention and learning are culturally situated, reflective of the values of the school system in which the teacher operates. This also exploits the power of international comparative studies to reveal the distinctive features of a community's teaching practice (D. J. Clarke, Emanuelsson, Jablonka and Mok 2006; Hiebert et al. 2003) and the cultural specificity of teacher instructional choices (Leong and Chick 2011; Lepik, Pipere and Hannula 2012). We anticipate important insights from the comparison of the objects of teacher attention and consequent teacher learning in communities as contrasting as Australia, China and Germany.

Building on the findings from the pilot study, we propose two forms in which teacher knowledge construction can be socially visible: epistemic claims and adaptive practice (Hatano and Inagaki 1986); that is, either a declarative "claim to know (or not know)" (the individual's epistemic stance) or an observable (or recounted) change in the individual's practice (adaptive practice). This conceptualisation recognises both teacher declarative knowledge and refined teaching practice as consequences of the process of teacher learning, while expressing both in observable form and as arising from the practice of teaching rather than as prerequisite to that practice. The expert teacher is seen to be a sophisticated professional, optimally equipped to learn from their engagement in professional activity.

The project design

The conceptual framework underlying the research design takes teacher selective attention as its focal point. This construct mediates between personal, contextual and

instructional characteristics and the teacher learning that arises from their interaction in the course of teaching a lesson. This is set out in Fig. 1. Our primary goal is to generate data with respect to teacher selective attention and teacher learning, while anticipating the need to explain both their structure and any mechanisms or connections linking the two. To achieve this, data are required on teacher knowledge and beliefs, on class and school contextual characteristics, and on the content, structure and affordances of the Lesson Plan itself. The research questions reflect these emphases. In addition, a methodological challenge for any investigation of teacher-situated selective attention is the obligation to identify not only those objects and events to which a teacher attends but also the meaning they hold for the teacher. The research design requires teachers to indicate the objects of their attention performatively (through the adaptation and construction of lesson plans), rather than only through conventional self-reporting techniques.

Structurally, the project consists of two investigations, undertaken in parallel:

(i) a set of fine-grained case studies of individual teachers undertaken in each country to investigate the interaction between the teacher and the lesson in sufficient detail to reveal the mechanisms connecting teacher attention to teacher learning, and
(ii) a national online survey designed to identify patterns in teacher attention and consequent learning, and also to generate and test hypotheses concerning the objects or activities to which teachers attend and the form of consequent learning.

The two components (case studies and online survey) are complementary, each contributing explanatory information with respect to the other.

The research design in both components makes use of the following key elements:

(a) Purposefully designed lessons as a catalyst to facilitate teacher learning (D. M. Clarke and Roche 2014);
(b) A model of teacher knowledge (Ball et al. 2008);
(c) A model of teacher learning (D. J. Clarke and Hollingsworth 2002);
(d) Recent research into teacher planning (Roche, Clarke, Clarke and Sullivan 2014);
(e) High-end technology to generate fine-grained classroom data, utilising techniques such as video-stimulated interviews (D. J. Clarke, Mitchell and Bowman 2009); and
(f) An analytical framework to expedite the analysis of the online survey data (D. M. Clarke et al. 2015).

The research design shown in Fig. 3 was developed and trialled in the pilot study and now provides the basic structure for both the parallel case studies and the online survey. The online medium of the survey requires the replacement of the interview and video elements with questionnaire instruments, but the designs for the case studies and the online component are structurally isomorphic.

The mathematics lesson plans

Data generation and analysis in relation to both the case studies and the online survey will focus on the actions associated with the teaching of lessons. This includes the

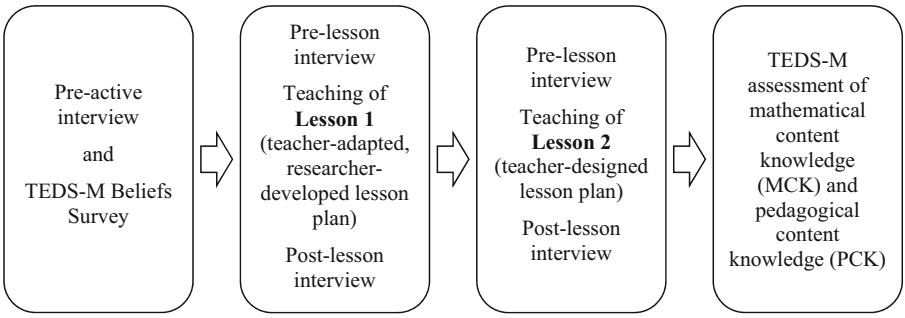

Fig. 3 The overall research design

teacher's thinking prior to the lesson, the teacher's actions during the lesson, the teacher's subsequent reflective thoughts about the lesson, and the consequences of this in the planning and teaching of a second lesson. In this view, the lesson plays a central role as a catalyst for teacher knowledge construction.

A series of mathematics lesson plans will be selected or developed by the research team in each country to maximise opportunities for teacher knowledge construction, to meet the data needs of the project, and to accommodate the curricular emphases and pedagogical norms of the participating countries. Each lesson plan will be represented using a standard template and covering an agreed mathematics topic (e.g. linear equations) across the three countries, but the lesson plans used in each country will be developed locally. For each of the provided lessons, teachers will be required to adapt the lesson to meet their purposes and the needs of their students, annotating the lesson plan to record these adaptations. They will also be required to use the same template in planning and documenting their follow-up lesson. The structure of the lesson template provides both a scaffold for teacher learning and a structure for project data collection. This design provides the basis for both the case studies and the online survey component.

The independent variables: measures of teacher MCK, PCK, beliefs and teacher demographics

The TEDS-M (Tatto et al. 2012) measured teacher Mathematical Content Knowledge (MCK), teacher Pedagogical Content Knowledge (PCK) and teacher beliefs. Permission was obtained from the International Association for the Evaluation of Educational Achievement (IEA) to use a selection of items with respect to all three constructs in the pilot study. Permission has been obtained to employ the same instruments in both components of the large-scale study. The TEDS-M beliefs items will be supplemented by items developed by the Australian project team to address a broader range of beliefs than was assessed by the original TEDS-M. The sample size and the statistical analyses possible in the online survey component of this larger study will allow us to build upon the pilot study (D. M. Clarke et al. 2015), and formulate and test hypotheses connecting MCK, PCK and teacher beliefs to teacher attention and consequent teacher learning. The influence of teacher demographics (such as teaching experience and professional development programs attended) and contextual factors (such as class size and school

characteristics) on both the direction of attention and on consequent teacher learning will be examined in the analysis of the online survey data.

The parallel case studies undertaken in each country

We will use data from the case studies to develop explanatory mechanisms for the associations identified in the survey. An adequate assemblage of case studies would have to address variations in teacher, grade level and topic. In each country, three researcher-developed lesson plans addressing different mathematical content will be provided to two teachers at each of three grade levels. Discussion between the teams in the three countries revealed that there were differences in when a given topic was typically introduced to students across the countries. In order to ensure the use of common topics across the three countries that were also grade-level appropriate, lesson topics were chosen targeting grades 5, 6 and 7 in Australia and Germany. The same lesson topics can also be taught in China but were judged to be appropriate for grades 4, 5 and 7. In all of the participating school systems, grades 4 to 7 span important organisational and curricular contexts, maximising the applicability of findings.

The specific lessons will be developed by the teams in each country during year 1 for use in year 2. Including the teacher-designed, follow-up lessons, this design will generate a dataset for each country of 36 lessons (in the form of 18 lesson pairs) with accompanying interviews. All lessons and interviews will be video recorded. In each interview identified in Fig. 3, data on teacher selective attention will be elicited through reference to actual teacher actions associated with the planning and teaching of a lesson. The post-lesson interviews will involve discussion stimulated by the video of the lesson just taught. The interview protocol employed in the pilot study can be used with minimal adaptation in the parallel case studies.

Case study teachers will be recruited who meet local criteria for competence, who have been teaching at least 5 years, and who have at least 1 year's previous experience of teaching the relevant grade level. Table 1 provides a summary of the case characteristics.

Online survey of mathematics teacher selective attention and consequent learning

In the online survey (see Table 2), teachers at three grade levels in each of the three countries will be invited to select a single lesson from an online lesson databank, and adapt the selected lesson plan to better address the needs of their students or local curriculum emphases. These lessons will cover similar content to those employed for the parallel case studies and include a similar range of instructional features, but need not be identical to the case study lessons, since the two analyses are differently

Table 1 Parallel case studies: case characteristics

Country	Grade level	Teacher	Lesson topic
Australia, China and Germany	Grades 5, 6 and 7 in Australia and Germany; grades 4, 5 and 7 in China	Two teachers per grade level	Three topics for each grade to be taught by each teacher at that grade level

Table 2 Online survey component: sample characteristics

Country	Grade level	Teacher	Lesson topic
Australia, China and Germany	Grades 5, 6 and 7 in Australia and Germany; grades 4, 5 and 7 in China	A minimum of 40 teachers per grade level per country	Nine researcher-designed lessons, three for each grade level

purposed, though complementary. Such a set of lessons will also accommodate the variation in both curricula and instructional norms across the three participating countries (D. J. Clarke, Wang, Xu, Aizikovitsh-Udi and Cao 2012).

The lesson plan template will accommodate teacher amendments and require a brief explanatory annotation by the teachers for each such change. The annotated lesson plan will be uploaded to the project website together with an additional rationale, setting out relevant contextual, organisational and resourcing details. The lesson will be taught and a questionnaire completed (involving prompts similar to the post-lesson 1 interview—Fig. 3). As with the case studies, teachers develop a follow-up lesson using the provided template and upload this together with a structured lesson rationale connecting the follow-up lesson to the first lesson. Through this act of instructional design, both the objects of the teachers' selective attention during the lesson just taught and their consequent learning are made visible. A further questionnaire is completed after the second lesson. Demographic data about each teacher will also be collected. Table 3 shows the corresponding data types.

An online sample of at least 40 teachers per grade level (120 teachers) is achievable in all three countries. Such sampling will afford both within-country and between-country analyses. Over-sampling is anticipated and some selective adjustment of the sample will be required to reflect national teacher demographics.

While the format of the online survey and the mode of delivery will be developed and trialled in Australia during year 1 of the project, the administration of the online

Table 3 Parallel listing of data types to be collected in case study and online mode

Case study	Online survey
Demographic survey	Elaborated demographic survey
Teacher adapted and annotated Lesson Plan 1	Teacher adapted and annotated Lesson Plan 1
Teacher rehearsal of the class activity (including all mathematical tasks)	Brief questionnaire completed at the point of uploading adaptation of Lesson 1
Pre and post Lessons 1 and 2 interviews (video and transcript)	Pre and post Lessons 1 and 2 questionnaires
Video recording of Lessons 1 and 2	Not required
Teacher-designed Lesson Plan 2	Teacher-designed Lesson Plan 2 (including rationale)
Teacher assessment (TEDS-M PCK and CK items) and beliefs questionnaire	Teacher assessment and beliefs questionnaire completed online
Student work samples	Not required
Artefacts from both lessons that are relevant (e.g. PowerPoint slides, student worksheets)	Artefacts from both lessons that are relevant (e.g. PowerPoint slides, student worksheets)

component will be managed locally in each country through those web-mediated channels most familiar to teachers in that country (e.g. the websites of professional associations). Both online and case study components will be undertaken during year 2.

Analysis plan

The goal of the case studies is evidence-based theory development tracing the structure and origins of teacher selective attention and the relationship between teacher attention and teacher learning. This activity will also provide a more detailed empirical warrant for connections identified in the online component of the study.

The data generated by the online survey will support statistical analysis using the analytical frameworks previously discussed. The analysis will identify patterns of association between teacher attention and learning (RQ1) and independent variables including teacher experience, MCK, PCK, teacher beliefs about the nature of mathematics and the goals and effective instructional methods of mathematics education, and teacher perceptions of their students (RQ2), lesson content (RQ3), grade level, school characteristics (RQ4), and country (RQ5). Multivariate path analysis will be undertaken on the full international data set (year 3), employing quantified forms of the constructs displayed schematically in Fig. 1. Although the model shown in the figure suggests that the only effects of the independent (exogenous) variables on teacher learning are indirect, being mediated by teacher selective attention, direct effects may also be identified. The data generated by the online survey will be used to model the associations between the various independent variables and teacher selective attention and learning.

In combination, the case studies and the online survey will provide the evidential base for documenting the connections between specific objects of teacher attention and forms of consequent learning. These connections constitute a key product of this project. The detail possible in the case studies will also offer insight into the constraints and affordances of the cultural, organisational and curricular contexts. In summary, we anticipate three levels of analytical product:

(i) patterns of association between teacher attention and consequent learning that may be specific to the participating countries (online survey);
(ii) details of process that suggest causal mechanisms by which teachers prioritise the objects of their attention and process observational information into forms of teacher knowledge (case studies); and
(iii) the function of contextual factors, including culture, organisation and curriculum in shaping teacher attention, learning and their connection (combination of both).

The final form of each analytical framework will also represent a key product of this research, potentially useful for scaffolding teacher attention and learning in different cultural settings.

Potential contribution of the project

It is our contention that a focus on on-going teacher learning through practice is a cost-effective approach to improve teacher learning and teaching quality, complementing the

learning that teachers can gain from professional development programs. Such an approach offers a viable pathway to significant national benefits in improved teaching quality. Our goal is to facilitate, in a sustainable and cost-effective way, the evidence-based optimisation of teacher learning during the design and teaching of lessons.

We posit teacher selective attention as a key mediating variable and suggest that the insights provided by this international comparative study will help to scaffold teacher attention and consequent learning within locally relevant models of quality teaching practice. Better understanding of how teachers learn through their daily professional activities will assist teacher educators in the partner organisations and elsewhere in promoting and facilitating that learning as an integral part of the teacher's professional practice. The three participating countries offer a range of contrasts and correspondences that maximise the insights likely from international (cross-cultural) comparison of teacher selective attention and teacher learning.

The combination of fine-grained, culturally situated case studies and large-scale online survey provides mutually informing benefits from each research approach. The complementary case studies undertaken in each country will provide fine-grained detail regarding the mechanisms and relationships by which existing teacher knowledge and values interact with teaching context to direct teacher attention and promote teacher learning in each setting. The research design, so constituted, offers the means to a new and scalable vision of teacher learning and its promotion.

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