MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2024, 20(4), em2418
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/14355

Designing a video-stimulated questionnaire about teachers' adaptive expertise in interdisciplinary mathematics and science teaching

Colleen Vale [1*], Gahyoung Kim [1], Wanty Widjaja [2], Joseph Paul Ferguson [2], Amanda Berry [3], Jan van Driel [4], Lihua Xu [2], Lam Pham [2]

[1] Monash University, Melbourne, AUSTRALIA
[2] Deakin University, Melbourne, AUSTRALIA
[3] Royal Melbourne Institute of Technology, Melbourne, AUSTRALIA
[4] University of Melbourne, Melbourne, AUSTRALIA

Received 23 November 2023 ▪ Accepted 15 January 2024

Abstract
Research investigating teachers' knowledge and practices aimed to improve student participation, engagement and achievement in mathematics and science has often used qualitative methods involving observation and analysis of lesson videos. Some researchers have used excerpts of videos in various ways to gather data about their participants' anticipated actions in the moment. In the current study, we aimed to track primary teachers' developing adaptive expertise when teaching interdisciplinary mathematics and science lessons over a two-year period. In this paper, we describe the processes followed to design a questionnaire that used episodes from videos of interdisciplinary mathematics and science lessons to construct multiple choice items. The adaptive expertise scoring for the items was reliable but this improved when including an open-ended question for participants to explain their selection of an action for the classroom moment captured in the video episode.

Keywords: adaptive expertise, video questionnaire items, video questionnaire design, interdisciplinary teaching, STEM

INTRODUCTION

Video-stimulated interviews have been used extensively to research teacher knowledge, teacher pedagogies, teacher noticing and teacher actions for teaching mathematics and teaching science (Alonzo & Kim, 2016; Campbell et al., 2023; Estapa & Amador, 2023; Vale et al., 2021). Other researchers have used video analysis tasks to pose open-ended questions to analyze teachers' pedagogical content knowledge or their capacity to 'act in the moment' (Chan, 2021; Copur-Gencturk & Rodrigues, 2021). In this paper, we discuss the process of designing a video-stimulated questionnaire that uses multiple-choice items to identify and monitor primary teachers' developing adaptive expertise (Anthony et al., 2015; Bransford et al., 2005; Hammerness et al., 2005; Timperley & Twyford, 2022a, 2022b; Yoon et al., 2019).

Adaptive expertise is considered important or essential for teachers to improve students' cognitive engagement, their problem solving and reasoning skills, their understanding of key ideas and processes, and their participation and achievement in mathematics and science (Bølstad, 2023; Osborne, 2023; Skilling et al., 2021; Tytler & Ferguson, 2023). However, we need to understand the changes in teachers' knowledge and practices over time that provide evidence of teachers' developing adaptive expertise. In order to do this we need to be able to monitor and measure their adaptive expertise. To date, research of adaptive expertise has focused on using classroom observation and video-analysis to identify the elements of adaptive expertise in mathematics or science lessons (Anthony et al., 2015; Bransford et al., 2005; Yoon et al., 2019). One of the aims of the current project, adaptive expertise in interdisciplinary mathematics and science, is to analyze

✉ colleen.vale@monash.edu **(*Correspondence)** ✉ jinny.kim@monash.edu ✉ wanty.widjaja@deakin.edu.au
✉ joe.ferguson@deakin.edu.au ✉ amanda.berry@rmit.edu.au ✉ Jvandriel@unimelb.edu.au ✉ lihua.xu@deakin.edu.au
✉ lam.pham@deakin.edu.au

Contribution to the literature

- Previous research has explored the concept of adaptive expertise in specific professional contexts; in this article we explore teachers' adaptive expertise in an interdisciplinary mathematics and science context.
- Previous studies of teachers' adaptive expertise and/or its components have used qualitative methods to investigate and gauge teachers' adaptive expertise. In this study we present the design of a questionnaire that included both closed and open items to gauge change in teachers' adaptive expertise over time.
- The use of video excerpts for closed questionnaire items enabled us to assess the possible teacher actions and levels of teachers' adaptive expertise when integrating mathematics and science in primary classrooms.

the development of primary teachers' adaptive expertise when teaching interdisciplinary mathematics and science lesson sequences over two years. A video-stimulated questionnaire is one method used in this project to collect data about the teachers' developing adaptive expertise. The video-stimulated questionnaire was used to collect data at the beginning of the project and will be used again at the end of the project. Video-excerpts for the items were generated from a sequence of interdisciplinary mathematics and sciences lessons about heart rate that were designed and trialed for the project. We propose that such an instrument is important for efforts to better understand and support the development of primary teachers' adaptive expertise and the capacity to meaningfully integrate mathematics and science in their schools.

Adaptive Expertise

Adaptive expertise is a critical component of quality teaching (Anthony et al., 2015; Bransford et al., 2005; Timperley & Twyford, 2022a, 2022b; Yoon et al., 2019). Adaptive expertise evolves as the teachers' focus shifts from self to students and from productively negotiating the common challenges to the complex challenges of teaching for student learning and wellbeing (Timperley & Twyford, 2022a, 2022b). Adaptive experts are able to quickly become accustomed to unfamiliar, unexpected and complex situations in the classroom as they strategically apply professional knowledge, innovation and creativity for particular teaching and learning purposes (Carbonell et al., 2014; Hatano & Inagaki, 1986; Hatano & Oura, 2003). Teachers as adaptive experts have a propensity to experiment with new and different teaching and learning activities as they purposefully seek to improve their teaching practices and learning outcomes for students (Anthony et al., 2015).

Bransford et al. (2005) identified innovation and efficiency as two main components of expertise, with adaptive experts exhibiting both innovation and efficiency in a balanced way, as reflected in the notion of the "optimal adaptability corridor" (Bransford et al., 2005, p. 49). Routine experts work efficiently in routine classroom situations and continue to use known tasks, procedures, and practices, while frustrated novices are keen to innovate but still need to develop efficient practices for standard situations.

Adaptive expertise as a construct has gained significant traction in education as it foregrounds teachers' responsiveness to the diversity of students in their classrooms and their needs as part of inclusive education (Anthony et al., 2015; Parsons, 2012; Soslau, 2012). In regard to science pedagogy, Crawford et al. (2005) align adaptive expertise as a disposition with 'excellence in science teaching' (p. 3). Such teachers undertake causal and data-driven forward reasoning through self-regulation and cognitive flexibility to address student learning needs. Yoon et al. (2015, 2019) argue that 'high quality teaching' (p. 903) in science manifests as adaptive expertise as the combination of flexibility, deep-level understanding and deliberate practice. Suh et al. (2023) propose that such adaptive expertise is necessary for teachers to be able to effectively induct students into the epistemic practices of science, which supports the development of student disciplinary-specific agency. The research situation is similar in regard to mathematics education, with Baldinger and Munson (2020) suggesting that adaptive expertise is aligned with 'ambitious teaching practices' (p. 1) in mathematics, with such expertise emerging from a process of co-construction among teacher colleagues who share their professional experiences to improve practice. The results of such teacher adaptive expertise, Sherman (2020) argues, are increased opportunities for students to express their mathematical knowledge and skills in meaningful ways as elicited by responsive teachers.

The adaptive expertise framework developed by Yoon et al. (2019) in a science teaching context (see **Table 1**), was used in the current study to design the video-stimulated questionnaire. The framework uses three main constructs: flexibility, deep-level understanding and deliberate practice. *Flexibility* is manifested in the teachers' ability to integrate aspects of their knowledge in relation to the teaching act with the goal of improving student outcomes while responding to their specific contexts. This may involve acknowledging and recognizing cultural and gender diversity of students as well as knowledge of their prior learning (Anthony et al., 2015; Beltramo, 2017). *Deep-level understanding* involves

Table 1. Adaptive expertise components (Yoon et al., 2019, p. 897-898)

Component
Flexibility: The ability to opportunistically plan, change enactments faster than non-experts, and flexibly and critically apply their knowledge to new situations while constantly learning.
Deep-level understanding: It addresses the need to not only have acquired content and pedagogical knowledge, but to have a deep understanding of it in order to use such knowledge effectively.
Deliberate practice: It addresses the need for teachers to receive feedback about and reflect upon their teaching either directly from their observations, from student outcomes, or from outside perspectives, with the intent to shift their practice based on feedback and reflection.

the teachers' ability to quickly recognize meaningful patterns, allowing them to attend to deeper-level problem solving and in turn students achieving at a higher level. The ability to respond to unexpected issues that arise in teaching and to act effectively in the moment is a manifestation of a deep level of understanding. This is evident when the teacher is able to make connections with students' prior knowledge and other concepts that build or address deeper-level knowledge construction or problem solving. *Deliberate practice* concerns the teacher's ability to engage in reflection during or after the lesson when reviewing the lesson individually or with a co-teacher. Deliberate practice involves conscious deliberation of teacher actions including the use of regulation processes to ensure cognitive engagement of all students (Valli, 1997; Yoon, et al. 2009).

Teacher Noticing & Acting-in-the-Moment

Adaptive expertise relates closely to the practice of teacher noticing of critical moments and the actions they take to enhance student engagement and learning (Carbonell et al., 2014; Chan et al., 2021; Choy & Dindyal, 2021; Pynes et al., 2020; van Es & Sherin, 2021). Teachers with adaptive expertise draw upon their knowledge of the socio-cultural background of their students in order to act in culturally inclusive and responsive ways (Anthony et al., 2015). Opportunities for teacher noticing of students' engagement and thinking occur when the teacher orchestrates whole-class discussions and observes and interacts with small groups of students or with individual students whilst working on tasks. According to Stockero et al. (2017), noticing requires the teacher to discriminate between different student actions to identify those that will create learning opportunities. Noticing therefore is important for providing opportunities for teachers' responsive actions to be focused on students' ideas (van Es & Sherin, 2021). The actions of teachers during these critical moments in mathematics or science lessons, as noticed by the teacher, are indicators of teachers' enacted pedagogical content knowledge (Campbell & Yeo, 2023; Chan, 2021; Estapa & Amador, 2023; Han et al., 2023; Kersting et al., 2012). They are also indicators of the nature or level of routine or adaptive expertise (Bransford et al., 2005, Yoon et al., 2019).

The research literature on acting in the moment concerns the nature of the teachers' interactions with students, with questioning strategies a key focus (Campbell & Yeo 2023, Chapin et al. 2009, Fraivillig et al. 1999, Liljedahl, 2016; Mason, 2010; Tytler & Aranda 2015). Questions that enable the teacher to explore what the student(s) are thinking and create a conjecturing classroom atmosphere enables students to become critically aware of their own learning (Mason, 2010). Fraivillig et al. (1999) identified three effective questioning strategies when interacting with individual students or during whole-class discussion: eliciting, supporting and extending questions. Tytler and Aranda (2015) identified three broad purposes for discursive moves in science lessons, which relate to the framework of Fraivillig et al. (1999): eliciting and acknowledging student responses, clarifying student ideas and extending student ideas. Similarly, Chapin et al. (2009) identified 'five productive talk moves' to use for whole-class discussions in mathematics lessons: revoice, repeat, reasoning, adding on and wait time. All these studies highlight the importance of noticing the various ways in which students engage with the mathematical or scientific task and the teacher using questioning and discourse strategies that attend to student reasoning and understanding. Studies of teacher noticing and acting in the moment informed the design of our video-based questionnaire for both selecting episodes, designing the questionnaire items and analyzing teacher participants' responses.

Methodologies Used for Analyzing & Assessing Adaptive Expertise

Many of the studies of adaptive expertise and teacher noticing discussed above have used qualitative methods (Alonzo & Kim, 2016; Chan, 2021; Copur-Genkturk & Rodrigues, 2021) such as, teacher self-reports of their teaching in interviews or reflection journals, researcher and colleagues' observations of teaching, and video records of the teacher's lessons and colleagues' lessons. A number of studies employed video excerpts from recorded lessons as stimuli for invoking teachers' noticing and reflection. Alonzo and Kim (2016) selected video clips of teachers' lessons showing unexpected student thinking for interviews of other teachers to investigate their contingency actions, that is, actions in the moment. Chan (2021) used video in two different ways to collect data about pre-service teachers' noticing and pedagogical knowledge. In the first study, Chan

(2021) used video-tagging, that is, pre-service teacher participants tagged specific moments of the video clip of a practicing teacher's science lesson and explained why they selected this moment. In the second study, Chan (2021) showed selected video excerpts of science lessons to a group of participating pre-service teachers and the researcher paused the video when "emergent student thinking occurred" (p. 154). The pre-service teachers were required to think in the moment and formulate a question to ask the student in the video episode. In each of these studies, the researcher used qualitative coding of the pre-service teachers' responses to analyze their pedagogical content knowledge and potential enactment of this knowledge.

Copur-Genkturk and Rodrigues (2021) conducted a national survey of mathematics teachers' noticing of content-specific teaching and learning events that occurred in selected video episodes. The teachers watched four short videos and responded to four open-ended questions that asked them to report on the three most significant events that they noticed in each video. Teachers' responses were coded to distinguish the propensity of teacher noticing content-specific (students' mathematical thinking or teacher's pedagogy) or non-content specific moments (e.g., classroom climate). Each response was assigned to one of four categories: non-mathematical events; description of the mathematics event; analysis of students' mathematical thinking; and identifying a key teaching and learning issue. They argued that watching videos of an unknown teacher that is recognizable as authentic avoids teachers being intimidated by analysis of their own actions and allows study participants to be more critical of teacher actions.

RESEARCH PROJECT

The aim of the longitudinal project is to improve theoretical and practical understanding of the nature and development of primary teachers' adaptive expertise in interdisciplinary mathematics and science using a co-plan, co-teach and co-reflect approach. One of the main research questions was to determine the extent of the development of their adaptive expertise over two years.

The study uses a mixed-method longitudinal research design. Pairs of teachers in Years 4-6 classrooms from four schools will teach the same two sequences of STEM lessons twice over two years. The two sequences of STEM lessons designed for the study were *keep your finger on the pulse* and *journey through space* (Hughes et al., 2022). In this paper, we discuss the processes of designing and validating the video-based questionnaire and highlight the methodological issues in identifying primary teachers' adaptive expertise. This questionnaire using video-excerpts with multiple-choice items along with open-ended explanations will be used to:

- identify evidence of the three characteristics of adaptive expertise–flexibility, deep-level of understanding and deliberate practice (Yoon et al., 2019);
- identify variation in primary teachers' adaptive expertise; and
- compare primary teachers' adaptive expertise over the two-year period, that is at the beginning and end of their engagement in the project.

Questionnaire Design

Since the purpose of collecting data is to evaluate teachers' developing adaptive expertise, responses to critical moments were used to compare components of their expertise prior to commencement of the project and will be used again at the end of the project. We followed the advice of Copur-Genkturk and Rodrigues (2021) and used video excerpts of authentic teacher and student actions that would be likely to occur when teaching the project's STEM lessons. *Keep you finger on the pulse* lessons were taught in a year 5 class in the pilot study and videos of these lessons were used to select excerpts of interactions between the teacher and their students to design items. There were three lessons in the sequence.

In the first lesson the students explored heart rate, what it is, how to measure it and how it changes in different situations. The science learning goals concerned understanding the purpose of the internal circulatory system to distribute energy around the body and the way in which it aids the survival of mammals. The mathematics learning goals concerned measuring heart rate and understanding and comparing rates. In the second lesson the students revisited the diversity of their heart rate when undertaking different activities and explored the diversity of heart rates in their class. They planned an activity that they thought would increase their heart rate by 50%. The science learning goals included understanding that heart rate can increase and decrease according to activity and that it varies with age. The mathematics goals included measuring heart rate, calculating 50% increase and developing understanding of percentage. In the third lesson the students planned and conducted an experiment to test an activity that they thought would increase their heart rate by 50%. The science goals included planning and conducting an experiment and revisiting the function of the heart and reasons for variation in heart rate for different activities. The mathematics learning goals included developing problem solving and reasoning skills, calculating 50% increase, collecting and analyzing data, and checking reasonableness of the data and their findings.

The lessons were co-taught by two teachers as we proposed that co-planning, co-teaching and co-reflecting would enhance teachers' development of deliberate practice, one of the components of adaptive expertise. Two cameras were used to record the lessons: one camera focused on one of the teachers, and a second 360° camera focused on the students and second teacher.

Principles of Questionnaire Design

In this section we discuss the principles of questionnaire design before describing the process we followed to design video items about adaptive expertise. Questionnaire items need to be explained and justified using evidence of validity and reliability (Bryman, 2016; McMillan & Schumacher, 2010). Face validity involves establishing that the item matches with the concept in question. This was established in our study by using members of the research team to determine whether the item reflects the particular concept under investigation (Bryman, 2016). According to McMillan and Schumaher (2006), construct validity is evident when there is a clear theoretical framework informing the instrument design and all relevant constructs of the theory are included. In this study, we employed the adaptive expertise framework developed and validated by Yoon et al. (2019). Processes that can be followed to test construct validity include examining the relationship between the content of items and the content of the theoretical framework. Concurrent validity involves examining participant explanations and patterns of response to determine whether these responses are consistent with intended interpretations, and to examine differences between groups of participants whom you expect to respond differently (Bryman, 2016). In our questionnaire design, we did this by trialing the draft questionnaire with a small group of primary teachers from another school.

Reliability refers to the consistency of the measure of the concept that includes testing for stability, internal reliability, and inter-rater reliability (Bryman, 2016). Since stability involves testing to determine if the results are stable over time and for our study we want to use the instrument to test for changes over time, we have not tested the instrument for stability. Internal reliability measures consistency of responses. In this case, the four multiple choice options for each question were given a score of one to four to show the level of adaptive expertise. Inter-rater reliability involves testing for consistency of ratings among the researchers for the options in multiple choice items. The requirements for validity and reliability were included in the design process for the video-based items for the questionnaire.

Process of Questionnaire Design

The following steps were followed by the research team to select and design each item for the questionnaire:

1. Independently viewing the first two lesson videos to identify students' mathematical and scientific reasoning that could challenge teachers' ability to respond to students.
2. Using a spreadsheet to record critical moments selected by research team members, indicate the connection to the theoretical framework and suggest possible questions.
3. Team meeting #1 to compare selected critical moments and discuss and relate these moments to theoretical framing of adaptive expertise.
4. Compiling possible video excerpts to create a common list for final discussion.
5. Team meeting #2 to discuss question structure: multiple choice or open-ended.
6. Drafting multiple-choice options and open questions about each participant's selection of video items.
7. Team meeting #3 to make the final selection of video items and the wording of the multiple-choice options for each item.
8. Ranking the multiple-choice options as evidence of adaptive expertise by each researcher and reaching agreement on the level of adaptive expertise for each option.
9. Trialing the questionnaire with practicing teachers.

Step 1 to step 4 involved establishing construct validity of the items being designed, whilst step 5 to step 7 concerned establishing both construct validity and internal reliability of the multiple-choice options. Inter-rater reliability was tested during step 8 and concurrent validity and internal reliability were tested during a trial with practicing primary teachers in step 9.

Construct Validity & Internal Reliability

Four members of the research team viewed the lesson videos for the first two lessons in the sequence. Each researcher entered information about the selected episode of up to one minute into a spreadsheet. This information identified: the lesson and video source; the time of the episode during the lesson and length of time up to one minute; a description of the context for the selected episode; the relevant adaptive expertise component and possible question or questions (either multiple choice or open-ended). **Figure 1** provides an example of an episode recorded during a whole class discussion about how to measure heart rate using your pulse. In this case, the researcher selected 'deep-level understanding' as the adaptive expertise component and drafted two open-ended questions.

In the first meeting (step 3) to compare episodes to use in the questionnaire, the researchers also began discussing the way in which we would phrase the questions to identify the teachers' levels of adaptive expertise. The first rows in **Figure 2** show the episodes selected by each of the four researchers from the first two lessons.

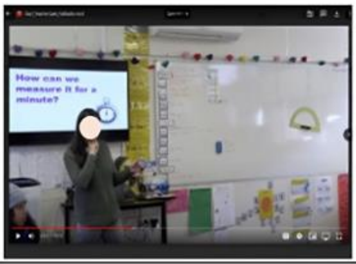
Lesson	Video file name	Time	Screen shot	Description	AE components	Possible questions
Week1	Day1_TeacherCam_FullAudio.mp4	24:06-25:08		Teacher asked "Will we count every single beat for a whole minute?". One student: Yes. Teacher: "We are going to sit there for a whole minute?" Student: Yeah...Teacher: Hm... Student: No,.. Yes... we are going to measure for 10 seconds and then multiply that by 6..... Teacher: Why 6?"	Deeper-level of understanding	How would you make connections that build deeper-level of knowledge of students based on this episode? What questions would you ask?

Figure 1. Spreadsheet used to record critical moments from lesson video (Source: Authors' own elaboration)

* ●: selecting, ◎: adding, ○: deleting

		Week 1																Week 2																
Moment		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1st individual selecting (33)	R1			●	●	●			●			●	●		●	●				●	●		●	●	●			●	●			●	●	
	R2				●			●															●							●				
	R3	●	●							●				●			●	●				●				●	●				●			●
	R4						●				●								●				●											
1st discussion																																		
2nd individual selecting (23)	R1			●	●	○	◎		○			●	●		○	●	◎			●	●		●	●	●			●	○			●	●	
	R2				●		◎	●				◎											●							○		◎		
	R3	○	●		◎					●		◎		●			●	○				●	◎			○	●				●	◎		○
	R4			◎			●				●						◎		○				●				◎							
3rd Group selecting (8)	All			●	●		●					●					●						●				●					●		
Final Items (6)	All				●							●					●						●				●					●		

Figure 2. Comparing & contrasting individual researcher's selections of critical moments (*R1 is researcher #1) (Source: Authors' own elaboration)

There were variations of selected episodes and the research team discussed: the similarities and differences between the various selected episodes; their exemplification of an element of the theoretical framework (Yoon et al., 2019); and the representation of both mathematics and science concepts and reasoning, even though this was not included in the spreadsheet. It was agreed that we would review the video-recordings for a second time and revise our selection and components of the episodes if warranted (**Figure 2**).

At the next meeting (step 5), we agreed on six video-episodes to be used in the questionnaire: three from lesson 1 (episodes 4, 11, and 16) and three from lesson 2 (episodes 22, 26, and 31) (see **Figure 2**).

At the third meeting (step 7), we confirmed selection of these episodes for the questionnaire, which are described in **Table 2**, and agreed on the adaptive expertise component of the theoretical framework that each episode concerned. We also ensured that the video extract would not include the teacher's action in the moment (Chan, 2021); rather, the clip was stopped at the point, where the teacher in the video was about to decide about how to respond or what to do next (van Es & Sherin, 2021). The next step, which also concerned establishing construct validity, involved agreeing that each item would be a multiple-choice question together with an open-ended question to seek an explanation for the teacher's action of choice. The content of these options drew on the research literature concerning actions in critical moments (van Es & Sherin, 2021) and teacher questioning (Chapin et al., 2009; Fraivillig et al., 1999; Mason, 2010; Tytler & Aranda, 2015).

Three of the selected video clips provided opportunities to identify teachers' adaptive expertise with regard to their deep-level understanding; two concerned mathematics concepts (item 1 and item 2) and two concerned science concepts (item 2 and item 5). Two video clips concerned flexibility (item 3 and item 4) and one deliberate practice (item 6).

Item 1 (video clip 4) requires participants to exhibit a deep level of understanding of rates, ratio and proportional reasoning to show that they could elicit students' understanding of rates and explain and justify calculation of equivalent rates. For Australian students in year 5 and year 6, these mathematical concepts are advanced elements of the curriculum for rational numbers (Australian Curriculum, Assessment and Reporting Authority, 2022). The agreed set of multiple-

Table 2. Video clips of critical moments selected for adaptive expertise questionnaire

Item	VE	Descriptions	AE
1	Video 4*	Before class, the teacher planned an activity to count the heartbeat for 15 seconds and multiply by 4 to calculate the heart beats per minute (bpm). In this video clip, the teacher is recording a student's alternative method of finding beats per minute (bpm) without having to count for a full minute. Please watch the video.	DLU (M)
2	Video 11	After students measured their resting heart rate, they had to predict and measure the change in their heart rate as they undertook various activities such as walking, star jumping, and running. In this video clip, the teacher is responding to a student who has just calculated their bpm after walking for a minute, before doing star jumps for a minute. Please watch the video.	DLU (M&S)
3	Video 16	Recalling what they had learned in the previous lesson, the teacher discussed with the students the best way to measure heart rate that they used last week. In this video clip, a student asks the teacher whether the pulse rate would be slower near the neck compared to the wrist. Please watch the video.	Flexibility
4	Video 22	The teacher recorded the resting heart rate measured by the students in an Excel spreadsheet and shared it on the screen (see below). The minimum for the heart rate in the class was 60 bpm and the maximum was 120 bpm. The teacher discussed how to calculate the class average. In this video clip, the teacher is responding to a student who suggested that the average bpm for the class is 166.1. Please watch the video.	Flexibility
5	Video 26	After working out the class average for bpm, the teacher explores the notion of range with students. In this video clip, the teacher discusses with the class why heart rate is a range rather than a specific number. Please watch the video.	DLU (S)
6	Video 31	Students had to devise activities to increase their resting heart rate by 50%. In this video clip, the teachers are talking about their conversations with students about designing a 'fair' procedure to increase their resting heart rate by 50%. Please watch the video.	Deliberate practice

Note. *Video 4: Moment #4 in lesson 1 in **Figure 1**; DLU (M): Deep-level understanding of mathematics; DLU (M&S): Deep-level understanding of mathematics & science; DLU (S): Deep-level understanding of science; & VE: Video episode

choice options for this item included four productive talk moves (Chapin et al., 2009).

The video clip for item 2, was selected to measure the deep-level understanding of both mathematics and science that the participating teacher would use when interacting individually with the student in the video excerpt. This extract provided an opportunity for a teacher to elicit, support, and extend the student's understanding of variation in heart rate and the reason why it varies and their mathematical understanding of comparing different heart rates. The four multiple choice options used Fraivillig et al.'s (1999) mathematical and Tytler and Aranda's (2015) science discursive moves: eliciting, clarifying, supporting, and extending questions for students. One of the options was a controlling or close question (Liljedahl, 2016; Mason, 2010), a common action of novice teachers and routine experts.

The video clip for item 5 was selected to test participating teachers' DLU for science. It is an extract from a whole class discussion about the range in students' resting heart rate. In order to extend students' scientific reasoning, the participating teacher needs to know the factors that contribute to variation in heart rates aside from age while being mindful of maintaining respectful relationships between students. The options included for this video extract drew on the discursive moves in science framework (Tytler & Aranda, 2015).

Two video clips (item 3 and item 4) were selected to identify whether the participating teachers are able to demonstrate flexibility. For item 3, a student asked an unexpected question about heart rate and where it should be measured (the neck or the wrist), and for item 4 a student calculated the class average heart rate, which was outside the range of recorded heart rates. The issue for a teacher therefore is whether or not to ignore these moments or act on these moments. The decision is based on their knowledge of the individual student's level of understanding and their own understanding of either mathematics or science to be able to support or extend the student's understanding. The four options for item 3 draw on the Tytler and Aranda (2015) framework and include: an authoritative teacher telling option, an eliciting option, a clarifying student thinking option, and an option to extend students' scientific reasoning. Similar options are included for item 4: a close statement stating the student's calculation is incorrect, an authoritative action, where the teacher explains an average, an eliciting question to seek the student's explanation, and a reasoning question directed at the whole class (Fraivillig et al., 1999; Liljedahl, 2016; Mason, 2010).

The final video extract (item 6) was selected to indicate whether or not the teacher could demonstrate deliberate practice. In this video clip the co-teachers of the videoed lesson meet to discuss what the students have been doing and what to do next. For this item, each of the options indicate that the co-teachers have attended to the procedures that the students have followed in

Table 3. Item 6 deliberate practice & researcher ratings of multiple-choice (MC) options

Multi-choice options	Researcher rating							Mode	Mean score*	MC option scores**
	R1	R2	R3	R4	R5	R6	R7			
A. This is a problem. I think we need to stop the class and explain clearly to the students that they need to measure their heart rate before and after their activity.	L	L	L	L	L	L	L	L	1	1
B. Let's stop the class and find out from the students how they are measuring heart rate.	H	M	M	M	M	M	M	M	2.57	2
C. Let's take this up with the students in a discussion at the end of the lesson/beginning of next lesson when we look at their data together.	M	M	H	M	H	M	H	M	3.14	4
D. Let's go on and have a chat with each group to find out what measurements they are taking.	M	H	M	H	M	M	M	M	2.93	3

Note. *To calculate mean: L=1, M=2.5, & H=4 & Scores to be used for each option when measuring adaptive expertise of participants

Table 4. Item 1 deep-level understanding of mathematics & researchers' ratings of multiple-choice (MC) options

Multi-choice options	Researcher rating							Mode	Mean score*	MC option scores**
	R1	R2	R3	R4	R5	R6	R7			
A. Ask another student to repeat this procedure using their own words.	M	M	H	H	M	H	M	M	3.14	3
B. I, the teacher, would restate the procedure.	L	L	L	M	L	L	L	L	1.21	1
C. Ask a student to explain why this procedure would work.	H	M	M	H	H	H	H	H	3.57	4
D. Ask for another way to calculate beats per minute.	M	H	L	H	H	L	H	H	2.93	2

Note. *To calculate mean: L=1, M=2.5, & H=4 & Scores to be used for each option when measuring adaptive expertise of participants

their experiments to test their conjectures to increase their heart rate by 50%. However, the plan for actions, that is, the multiple-choice options, are different and include: further observation, authoritative actions of teacher telling, and eliciting and reasoning actions to extend students' understanding of changing pulse rates and conducting experiments.

Each multiple-choice item included an open-ended question, which asked the participating teacher to explain their selected action. As the questionnaire was completed online, participants could explain their selection orally rather than writing their explanation.

Inter-Rater Reliability & Convergent Validity

Even though we used a common set of literature on noticing and acting in-the-moment, we still needed to agree on the level of adaptive expertise that each of the multiple-choice options for each item demonstrated. Seven members of the research team rated each of the multiple-choice options for each item as high, medium or low levels of adaptive expertise. Whilst there was quite a lot of consistency with these ratings across the team for each of the items, there were some disagreements. The findings for inter-rater reliability for two items will now be described; firstly item 6, about deliberate practice for which there was a lot of agreement (see **Table 3**), and then item 1 for which there was some disagreement amongst researchers.

For item 6 (see **Table 3**) concerning teachers' deliberate practice, the researchers agreed that option A was the least adaptive action and would receive the lowest score (one) of adaptive expertise as this proposed action would involve the teacher "telling" the students about the procedure to follow. There was agreement that option B was not a good example of adaptive expertise, with all but one researcher rating it as medium. The mean score for the researcher ratings showed this to be a low indicator of adaptive expertise and more likely an example of routine expertise and was rated to receive the second lowest score for adaptive expertise (two). Option C and option D had similar distribution of responses as medium or high ratings by researchers, with the mode rating as a medium measure of adaptive expertise. When mean scores were calculated, option C recorded the highest mean score. This option indicates deliberate practice as the teacher refers to the co-teacher and indicates that students' perspectives will be included in the discussion. The options were then given scores according to the mean score of the researchers so that option C received the top score for adaptive expertise (four) and option D the second top score (three).

For item 1 (see **Table 4**), there was agreement about the least adaptive action (option B), where the participant selected the practice of repeating what the student said. So, this option was scored the lowest level of adaptive expertise (one). However, there was disagreement about the rating of the other three options (A, C, & D). Option A and option C involved asking another student to repeat the procedure in their own words and asking the student to explain their procedure. Both received high and medium ratings. Option D was

Table 5. Trial responses to item 1 (deep-level understanding of mathematics)

Participant	Answer	Option score	Explanation score
Rose	D. Ask for another way to calculate beats per minute.	2	2
Mia	C. Ask a student to explain why this procedure would work.	4	3
Marg	C. Ask a student to explain why this procedure would work.	4	3

Table 6. Trial responses to item 6 (deliberate practice)

Participant	Answer	Option score	Explanation score
Rose	C. Let's take this up with students in a discussion at end of lesson/beginning of next lesson when we look at their data together.	4	2
Mia	D. Let's go on and have a chat with each group to find out what measurements they are taking.	3	3

rated as high, medium and low by researchers. Some researchers argued that seeking further solutions meets the criteria for deep understanding and developing this capacity in students by exploring other solutions and reasoning. However, other researchers rated this action as low. They argued that taking the action in option A may send a signal to students that the students' response in the video episode may be incorrect and so closes down the thinking of students (Mason, 2010). Mean scores for these options showed that option C was the most highly rated and following discussion the research team agreed to rate this option the highest level of adaptive expertise (four).

Concurrent Validity & Internal Reliability: Trialing Questionnaire

The questionnaire was trialed by three primary teachers prior to trialing the lesson sequence *journey through space*. They had a diversity of teaching experience. Marg was the most experienced and had a leadership role in mathematics at the school, Mia was also an experienced teacher but had only returned to teaching earlier in the year, and Rose was the least experienced. The teachers were provided with the lesson plans for interdisciplinary sequence for *keep your finger on the pulse* prior to completing the questionnaire. In this section, we discuss the trial teachers' responses to item 1 (DLU mathematics) and item 6 (deliberate practice) that we discussed above as these items were the most and least controversial for the researchers regarding scoring for the level of adaptive expertise.

The three teachers' responses for item 1 are recorded in **Table 5**. Rose's explanation of selecting option D, suggests that this teacher attends to flexibility by asking for an alternative approach in calculating beats per minute rather than accepting the students' responses: "in order to provide students with other ways to see how this way of thinking works …" However, Rose did not choose option C of explaining the reasoning for this procedure before collecting other ways of calculating the heart rate. Instead, Rose is attending to providing opportunities for student voice: "Also to give other students an opportunity to speak up and offer their ideas." Mia and Marg selected option C, with both focused on checking and sharing students' understanding of the procedure for calculating heart rate:

> "I would ask the student to repeat to the class her idea and ask her to explain why she thinks this option would work. How does she know this would work?" (Marg).

> "This approach would provide a powerful way to reinforce the strategy. It would also allow me to check another student's understanding" (Mia).

Marg went on to explain: "We would then test her theory (count heartbeats for 10 seconds and times by six) to see what we come up with" to suggest another way that students could test this procedure. However, she seems convinced that this is the only way to calculate heart rate: "I will ask students how we could prove this method is correct." Whilst Mia's justification is focused on students' understanding, she does not seem to reveal her own deep-level understanding of mathematics as she did not indicate a follow up question to investigate other methods for calculating the pulse rate. So whilst both Marg and Mia initially score four for multiple choice option selected–meaning both demonstrated a deep level of understanding and therefore a key component of adaptive expertise–a more appropriate score for Marg and Mia based on their explanations would be three, as they did not indicate that they were open to using other methods for calculating heart rate.

Item 6 was designed to collect data about teachers' deliberate practice. Only two teachers in the trial responded to this item (see **Table 6**). The third teacher experienced technical difficulties with completing this item online. Rose chose option C and Mia chose option D. Both these options indicate the two teachers saw value in consulting with their co-teacher to reflect on students' procedures and understanding to determine the action they would take. In her explanation Rose was focused on whether or not students were accurately following the procedure for designing an experiment to increase the pulse rate by 50%: "... it's important to ensure that they are being measured consistently in order to get the most accurate results from the experiment." She also indicated that a whole-class discussion would enable students to "understand how variables may change" when conducting the experiments about heart rate. These responses indicate a high level of science discipline understanding. It is less clear how this teacher values reflection on their observations of student actions, thinking and outcomes, and how these observations would be used to conduct the whole-class discussion. Given that this item measures deliberate practice, the team agreed that the explanation score should be two.

Mia selected option D, observing the methods students were using, which is scored as three (developing adaptive expertise for deliberate practice). She explained that she valued observation of students as they worked in their groups and interacting with them to elicit the methods that they were using and their understanding of these methods: "I would interact with each group individually. Some groups may have already addressed the issue and would not need to be prompted." Mia would use these observations to make decisions about the actions she would take. Hence, she would be flexible in responding to the learning needs of the different groups of students. So, the team agreed that Mia's explanation should at least be scored three, in line with the researchers scoring for this multiple-choice option.

The multiple-choice options selected by the teachers when trialing the questionnaire showed some consistency in their interpretation of the video-episodes of critical moments and teacher actions by the researchers. However, it has shown that including the teacher's explanation for their selected multiple-choice option for each item in the questionnaire, provides more detailed data upon which to assess teachers' level of adaptive expertise. So, analysis for each item will include both scoring the option they selected and analyzing and scoring the explanation of their choice of option for the item to compare the adaptive expertise of participants in the study and to compare and measure change in adaptive expertise for each participant and the group as a whole over the two years of the project.

DISCUSSION & CONCLUSIONS

Previous studies of teachers' noticing of critical moments for students' learning in mathematics and science have used videos of other teachers' lessons to construct items for group discussion and individual reflection by teachers or pre-service teachers (Chan, 2021; van Es & Sherin, 2021) or to construct questionnaire items (Copur-Gencturk & Rodriques, 2021) to assess teacher noticing. In this study, we selected critical moments that occurred during interdisciplinary mathematics and science lessons and used these moments to develop multiple choice questionnaire items to assess the participating teacher's adaptive expertise. Through the design and trialing process, we realized that the action that teachers chose along with the reason for choosing this action was needed to determine the nature and extent of their adaptive expertise. As noted by van Es and Sherin (2021), since we selected the video episodes for the questionnaire, we are not assessing the teacher's capacity to notice critical moments as a measure of their adaptive expertise, only their actions, and their reason for selecting this action, for the moments provided as an indicator of their level of AE.

We discovered that there were many opportunities in the two recorded video lessons to construct the items for teachers to demonstrate an aspect of their adaptive expertise. When deciding on which episodes to use, we needed to select episodes that best fitted the three categories of adaptive expertise in Yoon et al.'s (2019). Designing the multiple-choice options for actions in the moment was challenging, and consistency of assessment of each item for the level of adaptive expertise by the researchers even more challenging. The researchers did not always agree about the level of adaptive expertise for each multiple-choice option. In the end, the mean rating by the researchers was used to score the options. It was agreed that we needed to include an open-ended question for each multiple-choice item so that teachers could provide their explanations. Trialing these items with a small sample of teachers enabled us to test our scoring of the multiple-choice items. We agreed that we needed to retain the open question along with the multiple-choice options, as some of the respondents' explanations did not align with the researchers' anticipation of their reasoning, and hence the nature or level of their adaptive expertise that might be accorded based on the multiple-choice options alone.

Author contributions: CV, WW, LX, & JvD: instrument design & data analysis; **GK:** data analysis & record-keeping; **JPF & AB:** instrument design, trial data collection, & analysis; & **LP:** data record-keeping. All authors have agreed with the results and conclusions.

Funding: This study was supported by the Australian Research Council as a Discovery Grant Project: DP210101171.

Ethical statement: The authors stated that the study was approved by Monash University Human Research Ethics Committee on 23 June 2023. Written informed consents were obtained from the participants.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Alonzo, A., & Kim. J. (2016). Declarative and dynamic pedagogical content knowledge as elicited through two video-based interview methods. *Journal of Research in Science Teaching, 53*(8), 1259-1286. https://doi.org/10.1002/Tea.21271

Anthony, G., Hunter, J., & Hunter, R. (2015). Prospective teachers development of adaptive expertise. *Teaching and Teacher Education, 49*, 108-117. https://doi.org/10.1016/j.tate.2015.03.010

Australian Curriculum, Assessment and Reporting Authority. (2022). *Australian curriculum (version 9.0)*. https://acara.edu.au/curriculum

Baldinger, E. E., & Munson, J. (2020). Developing adaptive expertise in the wake of rehearsals: An emergent model of the debrief discussions of non-rehearsing teachers. *Teaching & Teacher Education, 95*, 103125. https://doi.org/10.1016/j.tate.2020.103125

Beltramo, J. L. (2017). Developing adaptive teaching practices through participation in cogenerative dialogues. *Teaching and Teacher Education, 63*, 326-337. https://doi.org/10.1016/j.tate.2017.01.007

Bransford, J., Derry, S., Berliner, D., Hammerness, K., & Beckett, K. L. (2005). Theories of learning and their roles in teaching. In *Preparing teachers for a changing world: What teachers should learn and be able to do* (pp. 40-87). Jossey Boss.

Bryman, A. (2016). *Social research methods*. Oxford University Press.

Campbell, C., Vale, C., & Speldewinde, C. (2023). Teaching science out-of-field: Beliefs and practices. *European Journal of Mathematics and Science Education 4*(2) 133-148. https://doi.org/10.12973/ejmse.4.2.133

Carbonell, K. B., Stalmeijer, R. E., Könings, K. D., Segers, M., & van Merriënboer, J. J. (2014). How experts deal with novel situations: A review of adaptive expertise. *Educational Research Review, 12*, 14-29. https://doi.org/10.1016/j.edurev.2014.03.001

Chan, K. (2021). Using classroom video-based instruments to characterize pre-service science teachers' incoming usable knowledge for teaching science, *Research in Science and Technological Education, 41*(1), 147-169. https://doi.org/10.1080/02635143.2021.1872517

Chan, K. Xu, L., Cooper, R., Berry, A. & van Driel, J. (2021). Teacher noticing in science education: do you see what I see? *Studies in Science Education 57*(1), 1-44. https://doi.org/10.1080/03057267.2020.1755803

Chapin, S. H., O'Connor, C., O'Connor, M. C., & Anderson, N. C. (2009). *Classroom discussions: Using math talk to help students learn, grades K-6*. Math Solutions.

Choy, B. H., & Dindyal, J. (2021). Productive teacher noticing and affordances of typical problems, *ZDM-Mathematics Education, 53*, 195-213. https://doi.org/10.1007/s11858-020-01203-4

Copur-Gencturk, Y., & Rodrigues, J. (2021). Content-specific noticing: A large-scale survey of mathematics teachers' noticing. *Teaching and Teacher Education, 101*, 103320. https://doi.org/10.1016/j.tate.2021.103320

Estapa, A., & Amador, J. (2023). A qualitative metasynthesis of video-based prompts and noticing in mathematics education. *Mathematics Education Research Journal, 35*(1), 105-131. https://doi.org/10.1007/s13394-021-00378-7

Fraivillig, J. L., Murphy, L. A., & Fuson, K. C. (1999). Advancing children's mathematical thinking in everyday mathematics classrooms. *Journal for Research in Mathematics Education, 30*(2), 148-170. https://doi.org/10.2307/749608

Hammerness, K., Darling-Hammond, L., & Bransford, J. (2005). How teachers learn and develop. In L. Darling-Hammond, & J. Bransford (Eds.), *Preparing teachers for a changing world: What teachers should learn and be able to do* (pp. 358-389). Jossey-Bass.

Han, C., Kim, H. J., Kwon, O. N., & Lim, W. (2023). Exploring changes of mathematics teachers' noticing in a video club: Identifying turning points. *International Journal of Science and Mathematics Education, 21*(3), 835-861. https://doi.org/10.1007/s10763-022-10251-z

Hatano, G., & Inagaki, K. (1986). Two courses of expertise. In H. Stevenson, H. Azama, & K. Hakuta (Eds.), *Child development and education in Japan* (pp. 262-272). Freeman.

Hatano, G., & Oura, Y. (2003). Commentary: Reconceptualizing school learning using insight from expertise research. *Educational Researcher, 32*(8), 26-29. https://doi.org/10.3102/0013189X032008026

Hughes, S., Russo, J., Mansfield, J., Green, A., Jones, D., Vale, C. & Berry, A. (2022) Co-designing integrated mathematics and science lesson learning sequences for primary education, *International Journal of Innovation in Science and Mathematics Education, 30*(4), 64-75. https://doi.org/10.30722/IJISME.30.04.005

Kersting, N., Given, B., Thompson, B., Santagata, R., & Stigler, J. (2012). Measuring usable knowledge: Teachers analyses of mathematics classroom videos predict teaching quality and student learning. *American Educational Research Journal, 49*(3), 568-589. https://doi.org/10.3102/0002831212437853

Liljedahl, P. (2016). Building thinking classrooms: Conditions for problem-solving. In P. Felmer, E. Pehkonen, & J. Kilpatrick (Eds.), *Posing and solving mathematical problems: Advances and new perspectives* (pp. 361-386). Springer. https://doi.org/10.1007/978-3-319-28023-3_21

Mason, J. (2010). Effective questioning and responding in the mathematics classroom. In G. Ineson, & H.

Povey (Eds.), *Debates in mathematics education*. Routledge.

McMillan, J., & Schumacher, S. (2006). *Research in education: Evidence-based inquiry*. Pearson.

Osborne, J. (2023). Science, scientific literacy, and science education. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of research on science education Volume III* (pp. 785-816). Routledge. https://doi.org/10.4324/9780367855758-30

Parsons, S. (2012). Adaptive teaching in literacy instruction: Case studies of two teachers. *Journal of Literacy Research, 44*(2), 149-170. https://doi.org/10.1177/1086296X12440261

Pynes, D., Empson, S., & Jacobs, V. (2020). Supporting teachers in the development of noticing children's mathematical thinking with a web-based tool. In H. Borko, & D. Potari (Ed.), *Teachers of mathematics working and learning together in collaborative groups* (pp. 676-683). International Commission on Mathematics Instruction.

Sherman, D. (2020). Eliciting student thinking in support of adaptive expertise in teacher candidates. *Journal of Higher Education Theory and Practice, 20*(11), 78-95. https://doi.org/10.33423/jhetp.v20i11.3765

Skilling, K., Bobis, J., & Martin, A. J. (2021). The "ins and outs" of student engagement in mathematics: Shifts in engagement factors among high and low achievers. *Mathematics Education Research Journal, 33*(3), 469-493. https://doi.org/10.1007/s13394-020-00313-2

Soslau, E. (2012). Opportunities to develop adaptive teaching expertise during supervisory conferences. *Teaching and Teacher Education, 28*(5), 768-779. https://doi.org/10.1016/j.tate.2012.02.009

Stockero, S. L., Rupnow, R. L., & Pascoe, A. E. (2017). Learning to notice important student mathematical thinking in complex classroom interactions. *Teaching and Teacher Education, 63*, 384-395. https://doi.org/10.1016/j.tate.2017.01.006

Suh, J. K., Hand, B., Dursun, J. E., Lammert, C., & Fulmer, G. (2023). Characterizing adaptive teaching expertise: Teacher profiles based on epistemic orientation and knowledge of epistemic tools. *Science Education, 107*(4), 884-911. https://doi.org/10.1002/sce.21796

Timms, M., Moyle, K., Weldon, P., & Mitchell, P. (2018). Challenges in STEM learning in Australian schools. *Policy Insights, 7*.

Timperley, H., & Twyford, K. (2022a). Adaptive expertise in educational leadership: Embracing complexity in leading today's schools. *Australian Educational Leader, 44*(1), 8-12.

Timperley, H., & Twyford, K. (2022b). Building a learning culture through the attributes of adaptive expertise. *Australian Educational Leader, 44*(2), 8-16.

Tytler, R., & Aranda, G. (2015). Expert teachers' discursive moves in science classroom interactive talk. *International Journal of Science And Mathematics Education, 13*, 425-336. https://doi.org/10.1007/S10763-015-9617-6

Tytler, R., & Ferguson, J. P. (2023). Student attitudes, identity, and aspirations towards science. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of research on science education volume III* (pp. 158-192). Routledge. https://doi.org/10.4324/9780367855758-8

Vale, C., Campbell, C., & White, P. (2021). Secondary teachers crossing subject boundaries to teach mathematics out-of-field: Evolving practices and beliefs. *Mathematics Education Research Journal, 33*(3), 589-612. https://doi.org/10.1007/s13394-020-00323-0

Valli. L, (1997). Listening to other voices: A description of teacher reflection in the United States. *Peabody Journal of Education, 72*(1), 67-88. https://doi.org/10.1207/s15327930pje7201_4

van Es, E., & Sherin, M. (2021). Expanding on prior conceptions of teacher noticing. *ZDM-Mathematics Education, 53*, 17-27. https://doi.org/10.1007/s11858-020-01211-4

Yoon, S. A., Evans, C., Miller, K., Anderson, E., & Koehler, J. (2019). Validating a model for assessing science teacher's adaptive expertise with computer-supported complex systems curricula and its relationship to student learning outcomes. *Journal of Science Teacher Education, 30*(8), 890-905. https://doi.org/10.1080/1046560X.2019.1646063

Yoon, S., Koehler-Yom, J., Anderson, E., Lin, J., & Klopfer, E. (2015). Using an adaptive expertise lens to understand the quality of teachers' classroom implementation of computer-supported complex systems curricula in high school science. *Research in Science and Technology Education, 33*(2), 237-251. https://doi.org/10.1080/02635143.2015.1031099