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Understanding how pre-service teachers design numeracy-rich activities in non-mathematic curriculum areas

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Abstract

Purpose – This study investigates the knowledge gaps of primary pre-service teachers (PSTs) in designing numeracy-rich tasks (NRTs) that incorporate real-life contexts across non-mathematics curriculum areas. It aims to understand the PSTs' competencies and the specific areas where they require further professional development.

Design/methodology/approach – The study involved 100 final-year PSTs from a primary education degree programme. These PSTs designed NRTs as part of a course focused on integrating numeracy across the curriculum. Data were collected from these assignments and analysed using a three-point analytical scoring scale and a knowledge framework to evaluate the presence of essential knowledge types in the designs.

Findings – The analysis revealed that while PSTs were adept at creating engaging activities focusing on teaching numeracy concepts, they struggled to effectively use numeracy to teach concepts in non-mathematics curricula. Most PSTs emphasised curriculum areas like Science and Geography in their NRTs. Significant gaps were noted in their ability to select suitable materials and in their understanding of integrating mathematics as a vehicle for teaching other subjects.

Originality/value – This study provides a unique insight into the challenges faced by PSTs in effectively integrating numeracy in non-mathematics curriculum areas. By identifying these knowledge gaps, the study contributes to enhancing the design of teacher education programmes, ensuring PSTs are better equipped to deliver comprehensive educational experiences.

Keywords Non-mathematics curriculum areas, Numeracy across curriculum areas, Numeracy rich tasks, Pre-service teacher knowledge

Paper type Research paper

1. Introduction

The global consensus underscores the critical role of numeracy in societal contributions, workforce enhancement, and personal decision-making, positioning it as a priority in educational systems worldwide. Numeracy's roots trace back over half a century, with its initial conceptualisation in the UK through The Crowther Report of 1959, which defined it as the ability to think quantitatively, like literacy. Over the decades, this definition has evolved and expanded. By 1998, researchers like Brown and colleagues emphasised numeracy as encompassing essential numerical skills such as mental arithmetic, written calculations, and a deep understanding of number facts across diverse settings (Brown *et al.*, 1998).

In 2001, the New Zealand Ministry of Education framed numeracy as a mathematical application in daily life, highlighting the importance of context in its practical use (Neill,

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2001). A pivotal moment in the conceptual evolution of numeracy occurred in 1997 during Australia's National Numeracy Strategy Conference. The conference's outcome, reinforced by a report from the Department of Employment, Education, Training and Youth Affairs (DEETYA), articulated numeracy as the effective application of mathematics in daily activities at home, in the workplace, and within the community. This broad interpretation was mirrored in the definition adopted by the Organisation for Economic Co-operation and Development (OECD) in 2012, which labelled numeracy as mathematical literacy—focusing on the capacity to understand, utilise, and interpret mathematics in various contexts (OECD, 2012). This comprehensive view encompasses not only knowledge and skills but also the behaviours and attitudes necessary for effective real-world application of mathematics, as advocated by scholars like Forgasz *et al.* (2017) and Durrani and Tariq (2012). This holistic approach to numeracy is critical, as it supports the integration of mathematical concepts into real-life scenarios, thereby enhancing student engagement and understanding. To foster such skills, teachers are encouraged to provide multiple opportunities for students to apply their mathematical knowledge across various contexts. Globally, teaching strategies to enhance numeracy have included integrating it across different curriculum areas and, in certain regions like South Africa, treating it as a standalone subject known as mathematical literacy (Modisaotsile, 2012). For instance, in Australia, teachers are encouraged to embed numeracy within all non-mathematical subjects, such as science and history, ensuring students can transfer their mathematical skills outside traditional math classrooms (ACARA, 2019).

The importance of teachers being skilled at creating and integrating Numeracy Rich Tasks (NRTs) throughout all areas of the curriculum cannot be overstated. However, challenges persist, such as the limited skills some educators have in designing effective NRTs. To address these gaps, educational researchers have developed models and provided professional development strategies aimed at enhancing teacher capabilities in this area. Goos's 2007 model, for instance, has been instrumental in offering principles for designing NRTs (Goos, 2007).

The present study builds on these foundations by utilising a knowledge framework proposed in 2022 to analyse the pre-service teachers (PSTs) design of NRTs (Getenet, 2022). The current research investigates the knowledge gaps PSTs face in creating effective numeracy tasks, aiming to identify specific areas where they require further professional development. The research question guiding this study is "What knowledge gaps do PSTs have for designing NRTs?"

The findings are expected to inform targeted training programmes that bridge theoretical knowledge with practical application, thus enhancing PSTs' ability to teach numeracy across various subjects. This exploration into the teaching and learning of numeracy not only resonates across different educational jurisdictions but also has global implications. The insights derived from such studies are crucial for the international educational community, providing evidence-based strategies to support PSTs in developing robust numeracy skills, crucial for their future roles as educators.

2. Literature review

2.1 Initial teacher educations and teachers' competencies

Teachers acquire knowledge and teaching competencies from diverse sources, as outlined in Grossman's (1990) research and Friedrichsen *et al.*'s (2009) distinctions. These sources include the teachers' own K-12 learning experiences, Initial Teacher Education (ITE) programmes, professional development, and teaching experiences. In this study, the authors focused on examining the competencies of PSTs in designing NRTs as developed in their ITE courses.

PSTs in ITE programmes are expected to possess the necessary competencies, skills, and confidence to teach in schools. These competencies include proficiency in various numeracy strategies, understanding numeracy teaching strategies, and applying them across different teaching areas (Australian Institute for Teaching and School Leadership [AITSL], 2018; Cooper *et al.*, 2017).

2.2 Numeracy across curriculum areas

When teachers are encouraged to identify and utilise numeracy learning opportunities in various non-mathematics curriculum areas, students' numeracy capabilities and critical thinking skills are likely to be enhanced (Bennison, 2015, 2022; Brown *et al.*, 1998). In the United States, for instance, numeracy is expected to be taught by all teachers across different subject areas (Ford, 2018). This approach is considered the most effective strategy for fostering numeracy skills in primary school students and holds greater potential for empowering students compared to approaches solely focused on mathematics curriculum areas (ACARA, 2019; Bennison, 2015). According to Bennison (2015), teachers need to fulfil three essential tasks to effectively teach numeracy across non-mathematics curriculum areas. Firstly, they must recognise numeracy learning opportunities present in various subject areas. Secondly, they need to possess the ability to design NRTs. Lastly, they must be capable of implementing these NRTs in their teaching practices. This article focuses specifically on the second task: the design of NRTs. The subsequent section explores the knowledge required to design NRTs across non-mathematics curriculum areas.

2.3 Teachers' knowledge of designing numeracy rich tasks

Teachers face the challenge of developing their knowledge and skills to effectively incorporate numeracy aspects across non-mathematics curriculum areas. ITE programmes are expected to equip PSTs with the necessary competencies, skills, confidence, and understanding of numeracy teaching. Previous studies, such as those conducted by Goos *et al.* (2010, 2013) and Getenet (2022), have highlighted the importance of teacher knowledge in designing NRTs. This includes the application of mathematics knowledge and context to integrate numeracy into non-mathematics curriculum areas. Other studies have emphasised the significance of having knowledge in at least one non-mathematics curriculum area (e.g. Beswick and Fraser, 2019; Ferguson-Patrick *et al.*, 2018; Phillips, 2002) and possessing design skills (Beetham, 2007; Hofer and Harris, 2010). These studies imply that designing NRTs requires specialised knowledge that is essential for effective implementation in the classroom.

In a recent study, Getenet (2022) identified four key areas of knowledge crucial for designing NRTs: mathematics content, non-mathematics curriculum area, activity design, and context. Each knowledge type is described with illustrative indicators, providing a framework for analysing teachers' designed NRTs and identifying their professional learning needs. The illustrative indicators for each knowledge type can also be used to assess and evaluate the quality of NRTs and can support teachers in designing effective NRTs that promote numeracy across non-mathematics curriculum areas (Getenet, 2022). Table 1 provides a summary of these knowledge types and their corresponding illustrative indicators, followed by further descriptions.

2.3.1 Mathematics content knowledge. Researchers agree that for teachers to be effective, they must have a strong foundation in both teaching methods and subject matter. Ball and colleagues, in 2008, highlighted the critical role of mathematics content knowledge for educators, proposing that teachers need proficiency in four distinct areas to effectively design and conduct mathematics lessons. Firstly, teachers should possess mathematical knowledge and skills applicable beyond the realm of teaching, which are valuable in various

Component	Description	Illustrative indicators
Mathematics Content Knowledge	The knowledge of mathematics concepts that are to be learned or taught and knowledge for teaching	The appropriate concept of mathematics Uses appropriate materials including concrete manipulatives, visual aids, digital resources, and real-world contexts to help students grasp abstract concepts through hands-on learning and visualisation Mathematics relevance – Age (year level) and prior knowledge
Knowledge of a non-mathematics curriculum area	The knowledge of a non-mathematics curriculum area/concepts that mathematics will be used to facilitate the learning	Focus on the curriculum area Mathematics is used as a vehicle to teach a non-mathematics concept Demonstrate and understand the concept Structure of the content
Knowledge of learning activity design	Knowledge of specific interaction of student(s) with other(s) using specific tools and resources focused on students' effective learning	Student-focused Relevance to students' lives Consideration of students' existing capabilities, including options for diverse students Provision of opportunities for discussion Use of relevant tools Inclusion of assessment strategies
Context	The knowledge of how classroom contexts and the diversity of students' learning styles and preferences offer opportunities to plan for effective learning experiences	Students' prior knowledge Age appropriateness Relevance to existing curricula Available potential tools The characteristics of the school system

Source(s): Getenet (2022, pp. 663-673)

Table 1.
Knowledge required to design NRT and their description

contexts but not exclusive to the educational sector. Secondly, educators must be familiar with the specific mathematical concepts that they will directly impart to students, facilitating a deeper comprehension of the subject. Thirdly, it is crucial for teachers to be able to recognise and understand the mathematical reasoning and growth of their students within the learning environment. Lastly, teachers require expertise in developing educational strategies tailored to the teaching of mathematics.

Getenet (2022) suggested that teachers' mathematics knowledge specific to designing NRTs includes understanding the concepts of mathematics (e.g. its definition), identifying the mathematics concepts to be used in teaching (e.g. helping students to understand the concept), and understanding students' levels of mathematical thinking.

2.3.2 Knowledge of curriculum areas other than mathematics. The earlier discussion highlighted that as students acquire discipline-specific knowledge informed by mathematics in subjects like history, civics, technology, economics, and business, their numeracy skills also develop. However, for primary school teachers, it is essential to grasp the content in these non-mathematical curriculum areas (such as history, science, geography, etc.) as well as understand mathematical concepts. This dual knowledge base enables teachers to engage in meaningful discussions with students and plan activities that are both relevant and effective (Beswick and Fraser, 2019). Furthermore, teachers need to demonstrate a thorough understanding of the content, structure, and instructional strategies specific to their teaching area (Getenet, 2022). They also need to possess the skill to organise this content into a coherent and effective sequence for learning and teaching.

2.3.3 Knowledge of designing learning activities. Effective learning activities are not only educationally significant but also concentrate on enhancing students' learning. Beetham (2007) described a learning activity as an interaction where students engage with others using specific tools and resources, aiming for certain outcomes. He highlighted the importance of designing these activities to be educationally meaningful and focused on maximising student learning. Beetham (2007) proposed five key elements for creating learning activities: authenticity, structured formality, promotion of reflection and concept internalisation, collaborative aspects, and student control over the learning process. Well-designed learning activities actively involve students and have been shown to lead to substantial positive educational results, as evidenced by studies such as those by Herrington *et al.* (2014) and Hofer and Harris (2010).

Following the suggestions of Beetham (2007), and Hofer and Harris (2010), Getenet (2022) identified a list of criteria that can be used as indicators to design learning activities. These indicators emphasise student engagement, relevance to students' lives, consideration of students' existing capabilities, including options for diverse students (students with a variety of cultural, socioeconomic, and educational backgrounds, possessing different numeracy abilities, learning styles, and experiences), providing opportunities for discussion, use of relevant tools, and inclusion of assessment strategies. Particularly, designing NRTs that are relevant to students' lives empowers students to use numeracy across various contexts including how mathematics is applied in shopping and media. When PSTs consider students' lives, teachers also investigate various aspects of culture (Bustamante *et al.*, 2016). Culturally responsive teachers are willing and able to interweave students' diversities and characteristics to designed activities and classroom instructional practices to meet students' learning objectives. In general, PSTs should note that numeracy skills can used for different purposes in different settings according to students' interests and lifestyles (Gal *et al.*, 2020).

2.3.4 Understand the context. Understanding context can help the designer suggest context-relevant teaching activities. In their study, Hailikari *et al.* (2008) and Smith and Ragan (2005) looked at context as classroom context and the student's context. Classroom context includes the presence of potential learning resources like technology, the nature of the school system, and how it aligns with current curriculums (Goos *et al.*, 2013; Steen, 2001). On the other hand, the context related to students encompasses their existing knowledge, age, perceptions of the subject, preferences, attitudes, and interests (Benson and Samarawickrema, 2007; Smith and Ragan, 2005). Understanding these contexts can support teachers in recognising the relevant mathematical concepts that can be used in non-mathematics curriculum areas (Callingham *et al.*, 2015). Therefore, teachers need to know the contexts (such as the diversity of students' learning styles and preferences) to design NRTs. Context knowledge was further described in relation to students' prior knowledge, age appropriateness, relevance to existing curricula, available potential tools and the characteristics of the school system.

Despite the necessity of these knowledge bases, it is important to recognise that integrating numeracy into certain non-mathematics subjects can be more challenging than in others. For instance, teachers often struggle to incorporate numeracy into English or literacy lessons due to a perceived shortage of suitable materials and resources (Koellner *et al.*, 2009). Similarly, Geiger *et al.* (2015) found that English curricula offer limited opportunities for teachers to weave numeracy requirements into their teaching. In contrast, Gough (2007) noted that science is a field where it is relatively easier to integrate numeracy through activities like generating and interpreting numerical data and creating and analysing data tables and graphs.

3. Method

3.1 Study context

This study took place at an Australian University within the School of Education, which prepares teachers for early childhood, primary, and secondary school levels. The focus of this study was on primary school PSTs in their final year of the degree programme. These PSTs are being trained to teach students from Foundation (with an average age of 5 years) to Year 6 (with an average age of 11 years). PSTs specialising in primary education are required to complete three core courses in mathematics curriculum and pedagogy. One of these courses specifically emphasises the integration of numeracy across various curriculum areas. As part of this course, PSTs were tasked with designing NRTs for non-mathematics curriculum areas outlined in the National Curriculum (Foundation to Year 6). These non-mathematics areas include humanities and social sciences (HASS) (including Geography and History), English, Science, The Arts (including music), Technologies (Design and Technologies and Digital Technologies), and Health and Physical Education (HPE). The current study was conducted within the framework of this course, with the author being one of the course designers involved in assessing the PSTs' assignments. The subsequent sections will provide a detailed description of the NRTs and their specific requirements.

3.1.1 The numeracy rich task. During the numeracy across curriculum course, PSTs were introduced to the concept of designing NRTs that align with their chosen non-mathematics curriculum areas and specific contexts. The PSTs' design of NRTs was guided by two criteria, each accompanied by sub-questions. A summary of these criteria is presented in Table 2.

Criterion 1 required PSTs to demonstrate their understanding of the identified mathematical concepts by explaining both the mathematical and non-mathematics concepts involved in their designed NRTs, supported by relevant examples. Additionally, PSTs were expected to identify and explain the relevance of these concepts to the National Curriculum.

Criterion 2 involved the design of NRTs within the identified non-mathematics curriculum area, focusing on teaching the intended concepts. The NRTs needed to showcase how mathematics could be integrated effectively within the chosen non-mathematics context. The mathematical activities within the NRTs should be relevant to the content being taught and should be tailored to suit the students' context. Furthermore, the activities were required to align with the outcomes outlined in the national curriculum. For instance, consider a scenario where a PST aims to design NRTs to help students understand

Criteria	Sub questions
Demonstrate understanding of the identified mathematical and non-mathematics concepts	Elaborate the numeracy concept involved with examples Elaborate the non-mathematical curriculum area concept involved with examples An explanation of the relevant content descriptor of the National Curriculum Inclusion of numeracy concepts that are relevant to the content, and the integrated non-mathematics curriculum area
Context, teaching and learning activity	Prepares a relevant teaching and learning activity that would further demonstrate how numeracy might be integrated within the selected non – mathematics curriculum area A detailed justification of the choice of activities and materials to support students to learn the non-mathematics curriculum area Describe the context of where your design could be implemented

Source(s): Table by author

Table 2.
Criteria and expectations of PSTs numeracy activities

the concept of chemical reactions involving fractions. In this case, the task should facilitate students' comprehension of the concept of chemical reaction by employing fractions as a means to deliver the understanding. The criteria and expectations in Table 2 ensure that PSTs understand concepts, prepare relevant activities, justify their choices, and describe implementation contexts that align with the criteria described in Table 1. For example, Table 1 emphasises the importance of understanding mathematical concepts. In parallel, Table 2 details the criteria and expectations for PSTs to demonstrate their understanding of both mathematical and non-mathematical concepts when designing NRTs.

3.2 Participants, data collection and analysis

3.2.1 Participants. Data were gathered from the assignment submissions of 100 PSTs enrolled in the final year of their teaching degree programme to become classroom teachers shortly. These students were enrolled in a mathematics education course focused on integrating numeracy across the curriculum while completing their assignments. These submissions originated from a single cohort of PSTs. The relevant university and school authorities granted ethical clearance to collect archived assignment data from these PSTs under the approval number H19REA032.

3.2.2 Data collection and analysis. The data analysis process consisted of two distinct steps. First, the assignment submissions were evaluated to meet the course requirements, and observations were noted for the subsequent analysis phase. During this initial evaluation, the numeracy tasks were graded according to the criteria outlined in Table 2, utilising a detailed marking rubric. A marking rubric is essentially a guide that outlines the criteria for grading.

For instance, one key criterion involved assessing the student's ability to demonstrate their understanding of specific mathematical and non-mathematical concepts. This required the PSTs to elucidate both the mathematical and non-mathematical concepts and insights related to their selected topics, potentially involving the definition of mathematical terminology or concepts, explanation of problem-solving skills or procedures, or the discussion on the application of mathematical tools within non-mathematical subjects. The insights gained from this first step informed the second step of the analysis, particularly in determining the considerations for each analytical scoring level, including the selection of criteria and evaluating the responses' adequacy using a knowledge framework.

The second step of the analysis, which is the focus of this study, involved examining the assignment submissions through the lens of a knowledge framework as detailed in Table 1. An analytical scoring system was employed, using a three-point scale (3 = considered, 2 = partly considered, 0 = not considered) to ascertain the presence of each type of knowledge and skill in the PSTs' designed NRTs. This approach aligns with suggestions from Trevisan *et al.* (2013) and Charles *et al.* (1987) for an analytical scoring scale in mathematics education assessment. An analytical checklist serves as a tool for data collection in educational, behavioural, and social sciences, aiming to measure task quality. Both Trevisan *et al.* (2013) and Charles *et al.* (1987) recommended a three-level scoring system (high, middle, and low performance) for task assessment. Specifically, for problem-solving tasks, Charles *et al.* (1987) proposed a three-point scale to evaluate the accuracy of the solutions, including the appropriateness of the plan, computational accuracy, and the correctness and labelling of the answer. Drawing from these methodologies, the current study utilised a three-point analytical scoring scale (3 = considered, 2 = partly considered, 0 = not considered) to identify each knowledge type present in the designed NRT, with each score level defined in Table 3.

The initial phase of the analysis, underpinned by the guidelines provided in the assignment rubric, enhanced the uniformity in scoring and the potential for enabling a reliable evaluation of the NRTs in the subsequent phase. Figure 1 displays a screenshot of a PST's created NRTs for a science experiment, accompanied by a detailed explanation of the activities designed to teach Year 5 science concepts and an illustration of the application of analytical scoring scales in assessing the NRT.

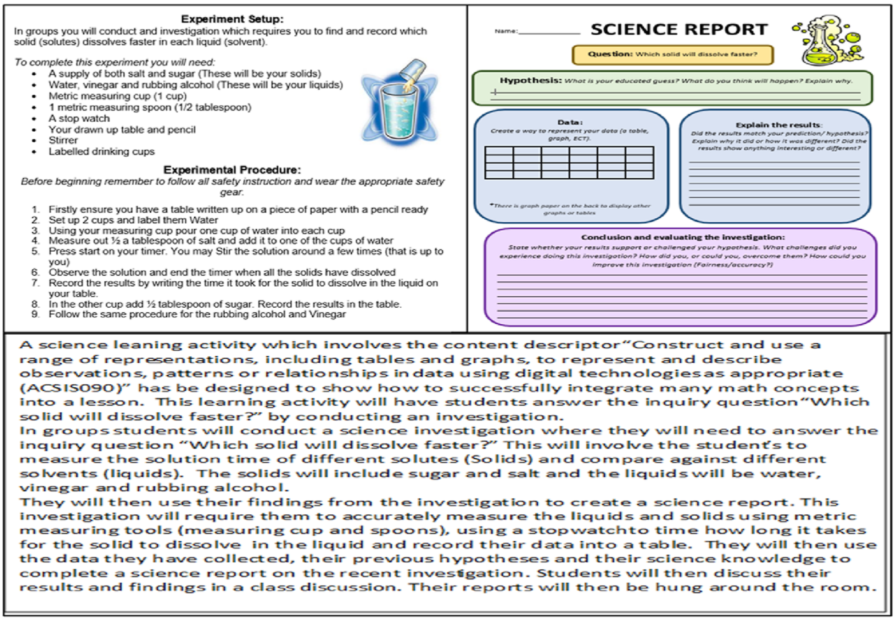
In the sample NRT, the quality of the activities was assessed on a three-point scale (3 = considered, 2 = partly considered, 0 = not considered). For example, the indicators, students' focus, relevance to students' lives, and consideration of students' existing capabilities, including options for diverse students, were judged to have been considered in this task. The indicators, including opportunities for discussion, use of relevant tools, and inclusion of assessment strategies, were deemed to have been partly considered. In addition, it was indicated that effective NRTs should use mathematics as a vehicle to deliver non-mathematics content. However, this was not the case in the example in Figure 1.

Finally, frequency table results were prepared for 100 NRTs. Similarly, the indicators of each knowledge type are shown in Table 1. The descriptions were used to evaluate PSTs' knowledge of mathematics content, non-mathematics curriculum area, activity designs and context. The designed NRTs contain further information: the non-mathematics curriculum

Table 3. Description of evaluation scales for numeracy-rich tasks

Scale	Description
Considered	The indicator is fully reflected in the designed numeracy rich task
Partly considered	The indicator is given due consideration but partially reflected in the designed numeracy task
Not considered	The indicator is not reflected in the designed numeracy task

Source(s): Table by author



Experiment Setup:
In groups you will conduct and investigation which requires you to find and record which solid (solutes) dissolves faster in each liquid (solvent).

To complete this experiment you will need:
- A supply of both salt and sugar (These will be your solids)
- Water, vinegar and rubbing alcohol (These will be your liquids)
- Metric measuring cup (1 cup)
- 1 metric measuring spoon (1/2 tablespoon)
- A stop watch
- Your drawn up table and pencil
- Stirrer
- Labelled drinking cups

Experimental Procedure:
Before beginning remember to follow all safety instruction and wear the appropriate safety gear.

1. Firstly ensure you have a table written up on a piece of paper with a pencil ready
2. Set up 2 cups and label them Water
3. Using your measuring cup pour one cup of water into each cup
4. Measure out ½ a tablespoon of salt and add it to one of the cups of water
5. Press start on your timer. You may Stir the solution around a few times (that is up to you)
6. Observe the solution and end the timer when all the solids have dissolved
7. Record the results by writing the time it took for the solid to dissolve in the liquid on your table.
8. In the other cup add ½ tablespoon of sugar. Record the results in the table.
9. Follow the same procedure for the rubbing alcohol and Vinegar

Name:__________ **SCIENCE REPORT**

Question: Which solid will dissolve faster?

Hypothesis: *What is your educated guess? What do you think will happen? Explain why.*

Data: *Create a way to represent your data (a table, graph, ECT).*

**There is graph paper on the back to display other graphs or tables*

Explain the results: *Did the results match your prediction/ hypothesis? Explain why it did or how it was different? Did the results show anything interesting or different?*

Conclusion and evaluating the investigation: *State whether your results support or challenged your hypothesis. What challenges did you experience doing this investigation? How did you, or could you, overcome them? How could you improve this investigation (Fairness/accuracy?)*

A science leaning activity which involves the content descriptor"Construct and use a range of representations, including tables and graphs, to represent and describe observations, patterns or relationships in data using digital technologiesas appropriate (ACSIS090)" has be designed to show how to successfully integrate many math concepts into a lesson. This learning activity will have students answer the inquiry question"Which solid will dissolve faster?" by conducting an investigation.
In groups students will conduct a science investigation where they will need to answer the inquiry question "Which solid will dissolve faster?" This will involve the student's to measure the solution time of different solutes (Solids) and compare against different solvents (liquids). The solids will include sugar and salt and the liquids will be water, vinegar and rubbing alcohol.
They will then use their findings from the investigation to create a science report. This investigation will require them to accurately measure the liquids and solids using metric measuring tools (measuring cup and spoons), using a stopwatchto time how long it takes for the solid to dissolve in the liquid and record their data into a table. They will then use the data they have collected, their previous hypotheses and their science knowledge to complete a science report on the recent investigation. Students will then discuss their results and findings in a class discussion. Their reports will then be hung around the room.

Figure 1. A PST's activities and description of activities in the NRT

Source(s): Figure by a student under ethics approval number H19REA032 area, year level, and the mathematics concepts used in the non – mathematics curriculum area. This information is presented in the results section.

4. Results

The results are presented in two sections. First, the identified non-mathematics curriculum areas and the dominant mathematics concepts across different year levels are presented. Second, PSTs' knowledge gaps are analysed to design NRTs based on the suggested description and indicators from Table 1.

4.1 Non-mathematics curriculum and mathematics concepts across year levels

PSTs were given the flexibility to choose and create NRTs suitable for any age or grade level from Foundation to Year 6, and applicable to curriculum areas outside of mathematics (non-mathematics). Table 4 presents a summary of how frequently these non-mathematics curriculum areas were selected across the different grade levels, indicating the number (n) of occurrences.

As shown in Table 4, most of the designed NRTs focused on Years 4 and 5 ($n = 27$) with less emphasis on Foundation, Years 1, 2 and 6 levels. Geography ($n = 21$) and science ($n = 34$) were the most frequently focused on non-mathematics curriculum areas in the designed NRTs. Mainly, Geography was used most frequently in Year 4 ($n = 7$), whereas science was used most often in Year 5 ($n = 12$). English and Design and Technologies ($n = 3$) were the least used.

The results in Table 5 show the frequencies of the identified mathematical concepts emphasised across year levels.

Although PSTs had multiple options to incorporate various mathematics concepts in their designed NRTs - including number concepts, mathematical operations (such as multiplication and division), and probability, they chose to focus only on a few specific areas. This is evidenced in the results in Table 5, which show that PSTs focused on a few areas of mathematics in their designed NRTs, such as interpreting data displays ($n = 25$) and graph information, location, and grid maps ($n = 27$). The designed NRTs focused on statistics and the measurement and geometry strands of the Australian Curriculum—Mathematics, but no NRTs were included in probability or multiplication.

	Year level							
Curriculum areas	*F*	1	2	3	4	5	6	Total
Arts	1	1	2	0	2	0	0	6
Design and technologies	0	0	1	1	0	0	1	3
Economics and Business	0	0	0	0	0	4	0	4
English	0	1	0	0	1	1	0	3
Geography	0	3	0	4	7	4	3	21
HASS – General	0	1	0	3	0	1	0	5
History	0	0	0	0	6	2	1	9
HPE	2	0	1	1	6	3	2	15
Science	4	2	3	6	5	12	2	34
Total	7	8	7	15	27	27	9	100

Source(s): Table by author

Table 4. Non-mathematics curriculum areas and year levels addressed in the NRTs

Table 5.
Mathematics concepts covered in the NRTs across year levels

Mathematics concepts	Year levels *F*	1	2	3	4	5	6	Total
Addition and subtraction	0	0	2	0	0	0	0	2
Angle measurement	0	0	0	0	0	2	0	2
Area Measurement	0	0	0	0	0	0	1	1
Collect and Classify data	0	0	1	0	0	0	0	1
Counting	1	0	0	0	0	0	0	1
Distance Measure	0	0	0	1	0	1	0	2
Financial Plans	0	0	0	0	0	4	0	4
Interpret data displays	0	0	0	5	5	11	4	25
Graph information, location, and grid maps	0	6	0	4	8	7	2	27
Length Measurement	2	0	2	0	3	1	1	9
Measurement - General	0	0	0	1	0	0	0	1
Order Numbers	0	0	0	0	1	0	0	1
Pattern and Relationship	0	2	0	0	2	0	1	3
Shapes	4	0	2	0	1	0	0	7
Shapes and Fractions	0	0	0	0	1	0	0	1
Solve word problems (numbers)	0	0	0	0	1	0	0	1
Time measurement	0	0	0	4	4	1	0	9
Using directions	0	0	0	0	1	0	0	1
Total	7	8	7	15	27	27	9	100

Source(s): Table by author

4.2 PSTs demonstrated knowledge of designing NRTs

Getenet (2022) argued that PSTs need a range of knowledge to design and implement effective NRTs. The first of these is mathematics content knowledge. The findings of PSTs' mathematics knowledge, as demonstrated in the NRTs, are shown in Table 6, where the frequency (n) indicates the number of NRTs fulfilling the indicator.

Most of the PSTs were careful to consider the mathematics concepts appropriate to teach the non-mathematics curriculum areas ($n = 53$), relevant to students' ages ($n = 55$), and relevant to students' year levels ($n = 61$) in their NRTs. However, most PSTs did not consider suitable materials to support the designed activities ($n = 45$). For example, primary school students engage better with visual and hands-on materials that are relatable and easy to manipulate, such as counting objects or simple charts, while learning the concept of data. However, PSTs often use data in Excel and complex visualisations that are beyond the comprehension level of their students.

The second skill and knowledge considered was PSTs' knowledge of a curriculum area other than mathematics. As shown in Table 7, there was an indication that half of the PSTs focused on non-mathematics curriculum areas in their designed NRTs ($n = 50$) than the mathematics concepts.

Table 6.
Mathematics content knowledge demonstrated in the tasks ($N = 100$)

Indicators	Considered (n)	Partly considered (n)	Not considered (n)
The right concept/definition of mathematics	53	27	20
Uses appropriate materials	27	28	45
Mathematics relevance – Age and prior knowledge	55	26	19
Relevance to year level	61	20	19

Source(s): Table by author

The degree of using mathematics as a vehicle to teach the non-mathematics curriculum concept was relatively low (n = 37). Although the results showed that most PSTs have the required non-mathematics curriculum area knowledge that should be embedded and the identified mathematics concepts, they were unsuccessful in using the mathematics concept to deliver the intended non-mathematics curriculum outcomes (see Tables 6 and 7). Table 8 shows the analysis results of PSTs' knowledge while designing the learning activities.

As shown in Table 8, PSTs valued the importance of relating activities to students' lives (n = 72) and designing engaging activities (n = 79) in their designed NRTs. For example, they have designed tasks that involve calculating the cost of items for a school fair or determining the probability of drawing a specific colour of marble from a bag, making the tasks relevant and interesting for students. There was less evidence that PSTs considered the importance of students' existing capabilities, including the option for diverse learners (n = 8) and the inclusion of assessment strategies (n = 4). They could rather include NRTs that consider diverse learners, such as designing tasks that allow for multiple solutions to cater to different learning styles or providing scaffolding for students with varying levels of ability.

Finally, the importance of PST's knowledge and understanding of contexts were analysed, and the result is shown in Table 9.

It is evident that while most PSTs partly addressed the context in their design of NRTs, such as considering students' prior knowledge, many highly valued the importance of relating the NRTs to the existing national curriculum (n = 83). For instance, they designed NRTs that align with curriculum standards, such as solving real-world problems involving fractions, decimals, and percentages, ensuring that the tasks not only engage students but also meet educational benchmarks.

Table 7. Non-mathematics curriculum area knowledge demonstrated in the tasks (N = 100)

Indicators	Considered (n)	Partly considered (n)	Not considered (n)
Focus on the non-mathematics curriculum area	50	31	19
Mathematics is used as a vehicle to teach the concept	37	43	20
Demonstrate and understand the concept	37	42	21
Structure of the content	37	45	18

Source(s): Table by author

Table 8. Analysis of learning activities (N = 100)

Indicators	Considered (n)	Partly considered (n)	Not considered (n)
Students focused	79	11	10
Relevance to students' lives	72	14	14
Consideration of students' existing capabilities, including options for diverse students	8	50	42
Provision of opportunities for discussion	28	45	27
Use of relevant tools	40	26	34
Inclusion of assessment strategies	4	59	37

Source(s): Table by author

5. Discussion

The research question guiding this study was "What knowledge gaps do PSTs have for designing NRTs?" To design effective NRTs, PSTs need four knowledge types: mathematics content, non-mathematics curriculum area, activity designs, and context (see Table 1). Each is discussed in relation to the gaps identified.

This study indicates that teachers need suitable mathematical knowledge for different situations, including areas of the curriculum not traditionally associated with mathematics. The findings show that PSTs thoughtfully selected mathematical concepts that matched the students' current understanding and appropriate grade levels when creating their NRTs, as detailed in Table 6. However, despite the recognised importance of employing suitable resources for teaching math concepts effectively—like using hands-on manipulatives to teach patterns, as highlighted in previous studies (e.g. Koellner *et al.*, 2009; Herrington *et al.*, 2014)—the PSTs did not prioritise incorporating relevant materials into their NRT designs. This was noted from the PSTs' description of the resources required to deliver the designed NRTs, which was also one of the requirements of their assignment, as described in Table 2. Designing NRTs requires the desire to embed the related mathematics concepts within numeracy tasks and appropriate resources that best support the implementation of the NRTs (Forgasz *et al.*, 2017).

Teachers must know the content of non-mathematics curriculum areas to effectively use mathematics concepts and then deliver the intended non-mathematics concepts. PSTs were also required to demonstrate this content knowledge in their assignment submission (see Table 2). In addition, teachers require knowledge of non-mathematics curriculum areas and mathematics content to use and provide the learning intended in those non-mathematics curriculum areas. However, this study results showed that most PSTs were less successful in using mathematics concepts to deliver the intended non-mathematics curriculum concepts (see Table 7). Despite research suggesting that mathematics should serve as a tool to enhance understanding in subjects outside of mathematics (for example, as argued by Phillips, 2002), this study found minimal use of mathematics to facilitate teaching concepts from non-mathematical curricula.

When designing engaging activities, PSTs recognised the importance of considering students' lives and engaging students in their activities. Despite an indication from PSTs that they did not consider the importance of students' existing capabilities, including the option for diverse students and the inclusion of assessment strategies (see Table 7). Research suggests that effective learning activities help students blend new concepts or skills with their pre-existing beliefs and abilities across different situations (Beetham, 2007; Hofer and Harris, 2010). Furthermore, well-designed learning activities can engage students more deeply in their learning process, leading to markedly positive outcomes (e.g. Herrington *et al.*, 2014).

Knowledge of classroom contexts and the diversity of students' learning styles and preferences offer opportunities to plan for effective learning experiences. This study

Indicators	Considered (n)	Partly considered (n)	Not considered (n)
Students' prior knowledge	26	49	25
Age appropriateness	59	25	16
Relevance to existing curricula	83	5	12
Available potential tools	32	26	42
The characteristics of the school system	24	30	46

Source(s): Table by author

Table 9. Analysis of context ($N = 100$)

investigated how numeracy activities were incorporated into authentic scenarios (such as those relevant to students' lives) in various non-mathematics curriculum areas and contexts. The PSTs lacked the experience to address these contexts in their design of NRTs (see Table 9). This could make it difficult for them to provide students with the necessary learning experiences to adapt their school knowledge to the outside world. However, there are suggestions, such as by Steen (2001), that for students to become numerate, they must engage with tasks that demand the use of mathematics in multiple contexts.

On the other hand, PSTs highly regarded the national curriculum in their activities, which is an expectation of teachers in Australian school contexts and the requirements of designing their NRTs by explaining the relevant content descriptor of the National Curriculum (see Table 2). It is encouraging that PSTs take account of the national curriculum in their NRTs as teachers at all grade levels, across all subject areas, are expected to support students in developing their numeracy capabilities (ACARA, 2019; Forgasz *et al.*, 2017). The author expected PSTs to incorporate numeracy activities into various non-mathematics curriculum areas. However, the results of this study showed that PSTs emphasised only a few non-mathematics curriculum areas, such as Science and Geography, when designing NRTs but gave less emphasis on other areas, such as English, design and technologies (see Table 4). In this regard, studies indicate that learning activities are most effective when they enable students to integrate new ideas or skills with their existing knowledge and capabilities across various scenarios (Beetham, 2007; Hofer and Harris, 2010). Additionally, learning activities that are thoughtfully designed can significantly increase student engagement in the learning process, resulting in notably better outcomes (for example, Herrington *et al.*, 2014). In essence, this research highlights the critical role of learning activities in bridging new knowledge with students' pre-existing skill sets and understandings in a range of contexts.

In addition to findings related to the four key areas of knowledge, PSTs focused only on a few mathematics areas in their designed NRTs, such as interpreting data displays, locations, and maps (see Table 5). This resonates with the findings of Gough (2007). Gough argued that making and reading data tables and graphs are common mathematics concepts embedded in many areas of science. PSTs' choices of a few selected non-mathematics curriculum areas perhaps have been influenced by a lack of necessary knowledge and capability to incorporate other mathematics concepts, such as probability, across other curriculum areas. This finding highlights the need for further steps to investigate this line of enquiry.

6. Limitations and future directions

There were at least two limitations to the findings of this study. Firstly, the analysis focused on tasks designed by PSTs, and a more thorough approach would involve observing the PSTs as they implement these tasks in real classroom settings. Secondly, the criteria used to dissect PSTs' knowledge revealed similarities among different framework components, such as mathematics content knowledge and knowledge related to non-mathematics curriculum areas. These similarities indicate a need for further refinement of identifying the elements of the knowledge types. Despite these limitations, the study offers valuable insights into identifying gaps and opportunities for integrating numeracy within non-mathematics subjects, and it proposes effective professional learning strategies for educators.

7. Conclusion

This study highlighted that for PSTs to contribute to students' numeracy competence, they need the knowledge of mathematics, non-mathematics curriculum area, activity design knowledge and skills and relevant contexts, and strategies to support teachers in developing this knowledge and skills. In addition, the procedure used in this study, supported by the knowledge framework, can be used to analyse the PSTs' designed NRTs, identify the knowledge and skill requirements for teaching numeracy across non-mathematics curriculum areas and identify their professional learning requirements. Relevant professional development of teachers focusing on this knowledge and skills could support them in integrating numeracy across non-mathematics curriculum areas and developing effective NRTs. The results of this study further showed that the PSTs were challenged to use mathematics as a vehicle to teach other curriculum areas because of their minimal knowledge, either in mathematics or non-mathematics content. Particularly, the PSTs were challenged to successfully use mathematics concepts to deliver the intended non-mathematics curriculum concepts. They tend to teach mathematics in the non – mathematics curriculum areas. This result suggests teamwork involving distinct mathematics and non-mathematics curriculum areas of teachers working collaboratively could facilitate the effective design of NRTs. Teachers working collaboratively on bringing together the mathematics and other non-mathematics curriculum areas knowledge taught in the classroom gave meaning to students in the context of other curriculum areas.

References

Australian Curriculum and Assessment Reporting Authority (ACARA) (2019), "The Australian curriculum", available at: https://www.australiancurriculum.edu.au/

Australian Institute for Teaching and School Leadership [AITSL] (2018), "Australian professional standards for teachers", available at: https://www.aitsl.edu.au/docs/default-source/national-policy-framework/australian-professional-standards-for-teachers.pdf

Ball, D.L., Thames, M.H. and Phelps, G. (2008), "Content knowledge for teaching: what makes it special?", *Journal of Teacher Education*, Vol. 59 No. 5, pp. 389-407, doi: 10.1177/0022487108324554.

Beetham, H. (2007), "An approach to learning activity design", in Beetham, H. and Sharpe, R. (Eds), *Rethinking Pedagogy for a Digital Age: Designing and Delivering E-learning*, Routledge, pp. 26-41.

Bennison, A. (2015), "Supporting teachers to embed numeracy across the curriculum: a sociocultural approach", *International Journal on Mathematics Education*, Vol. 47 No. 4, pp. 561-573, doi: 10.1007/s11858-015-0706-3.

Bennison, A. (2022), "Using zone theory to understand teacher identity as an embedder-of-numeracy: an analytical framework", *Asia-Pacific Journal of Teacher Education*, Vol. 50 No. 2, pp. 171-186, doi: 10.1080/1359866X.2020.1828821.

Benson, R. and Samarawickrema, G. (2007),"Teaching in context: some implications for eLearning design", in Atkinson, R.J., McBeath, C., Soong, S.K.A. and Cheers, C. (Eds), *ICT: Providing Choices for Learners and Learning. Proceedings of Ascilite Singapore 2007*, Centre for Educational Development, Nanyang Technological University, pp. 61-70.

Beswick, K. and Fraser, S. (2019), "Developing mathematics teachers' 21st-century competence for teaching in STEM contexts", *ZDM*, Vol. 51 No. 6, pp. 955-965, doi: 10.1007/s11858-019-01084-2.

Brown, M., Askew, M., Baker, D., Denvir, H. and Millett, A. (1998), "Is the national numeracy strategy research-based?", *British Journal of Educational Studies*, Vol. 46 No. 4, pp. 362-385, doi: 10.1111/1467-8527.00090.

Bustamante, R.M., Skidmore, S.T., Nelson, J.A. and Jones, B.E. (2016), "Evaluation of a cultural competence assessment for preservice teachers", *The Teacher Educator*, Vol. 51 No. 4, pp. 297-313, doi: 10.1080/08878730.2016.1186767.

Callingham, R., Beswick, K. and Ferme, E. (2015), "An initial exploration of teachers' numeracy in the context of professional capital", *ZDM*, Vol. 47 No. 4, pp. 549-560, doi: 10.1007/s11858-015-0666-7.

Charles, R., Lester, F. and O'Daffer, P. (1987), *How to Evaluate Progress in Problem Solving*, Reson, NCTM, VA.

Cooper, B., Cowie, B., Furness, J.A., Peter, M. and Bailey, J. (2017), "Mathematical reasoning and knowledge in initial teacher education (MARKITE)", *Teaching and Learning Research Initiative*, available at: http://www.tlri.org.nz/sites/default/files/projects/Final%20formatted%20report%20_Cooper%20and%20Cowie%28v3%29.pdf

Durrani, N. and Tariq, V.N. (2012), "The role of numeracy skills in graduate employability", *Education + Training*, Vol. 54 No. 5, pp. 419-434, doi: 10.1108/00400911211244704.

Ferguson-Patrick, K., Reynolds, R. and Macqueen, S. (2018), "Integrating curriculum: a case study of teaching global education", *European Journal of Teacher Education*, Vol. 41 No. 2, pp. 187-201, doi: 10.1080/02619768.2018.1426565.

Ford, K. (2018), "Persisting gaps: labor market outcomes and numeracy skill levels of first-generation and multi-generation college graduates in the United States", *Research in Social Stratification and Mobility*, Vol. 56 No. 2018, pp. 21-27, doi: 10.1016/j.rssm.2018.06.003.

Forgasz, H., Leder, G. and Hall, J. (2017), "Numeracy across the curriculum in Australian schools: teacher education students' and practising teachers' views and understandings of numeracy", *Numeracy*, Vol. 10 No. 2, pp. 1-23, doi: 10.5038/1936-4660.10.2.2.

Friedrichsen, P.J., Abell, S.K., Pareja, E.M., Brown, P.L., Lankford, D.M. and Volkmann, M.J. (2009), "Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program", *Journal of Research in Science Teaching*, Vol. 46 No. 4, pp. 357-383, doi: 10.1002/tea.20283.

Gal, I., Grotlüschen, A., Tout, D. and Kaiser, G. (2020), "Numeracy, adult education, and vulnerable adults: a critical view of a neglected field", *ZDM*, Vol. 52 No. 3, pp. 377-394, doi: 10.1007/s11858-020-01155-9.

Geiger, V., Forgasz, H. and Goos, M. (2015), "A critical orientation to numeracy across the curriculum", *International Journal on Mathematics Education*, Vol. 47 No. 4, pp. 611-624, doi: 10.1007/s11858-014-0648-1.

Getenet, S. (2022), "Teachers' knowledge framework for designing numeracy rich tasks across non-mathematics curriculum areas", *International Journal of Education in Mathematics, Science and Technology*, Vol. 10 No. 3, pp. 663-680, doi: 10.46328/ijemst.2137.

Goos, M. (2007), "Developing numeracy in the learning areas (middle years)", *Keynote address delivered at the South Australian Literacy and Numeracy Expo*, Adelaide.

Goos, M., Geiger, V. and Dole, S. (2010),"Auditing the numeracy demands of the middle years curriculum", in Sparrow, L., Kissane, B. and Hurst, C. (Eds), *Shaping the Future of Mathematics Education (Proceedings of the 33rd Annual Conference of the Mathematics Education Research Group of Australasia*, MERGA, Fremantle, pp. 210-217.

Goos, M., Geiger, V. and Dole, S. (2013),"Designing rich numeracy tasks", in Margolinas, C. (Ed.), *Task Design in Mathematics Education: Proceedings of ICMI Study 22*, ICMI, pp. 589-598.

Gough, J. (2007), "Make your school's numeracy-across-the-curriculum policy", *Australian Mathematics Teacher*, Vol. 63 No. 3, pp. 31-39, available at: http://hdl.handle.net/10536/DRO/DU:30007800

Grossman, P.L. (1990), *The Making of a Teacher: Teacher Knowledge and Teacher Education*, Teachers College Press, New York.

Hailikari, T., Katajavuori, N. and Lindblom-Ylanne, S. (2008), "The relevance of prior knowledge in learning and instructional design", *American Journal of Pharmaceutical Education*, Vol. 72 No. 5, pp. 1-8, doi: 10.5688/aj7205113.

Herrington, J., Reeves, T.C. and Oliver, R. (2014), "Authentic learning environments", in Spector, J.M., Merrill, M.D., Elen, J. and Bishop, M.J. (Eds), *Handbook of Research on Educational Communications and Technology*, Springer, pp. 401-412.

Hofer, M. and Harris, J. (2010), "Differentiating TPACK development: using learning activity types with in-service and pre-service teachers", in Gibson, D. and Dodge, B. (Eds), *Proceedings of Society for Information Technology and Teacher Education International Conference 2010*, AACE, pp. 3857-3864.

Koellner, K., Wallace, F.H. and Swackhamer, L. (2009), "Integrating literature to support mathematics learning in middle school", *Middle School Journal*, Vol. 41 No. 2, pp. 30-39, doi: 10.1080/00940771.2009.11461710.

Modisaotsile, B. (2012), "The failing standard of basic education in South Africa, Africa Institute of South Africa", *Policy Brief*, Vol. 72, pp. 1-7, available at: http://www.purpletod.co.za/docs/FAILING%20STANDARDS.pdf

Neill, W.A. (2001), "The essentials of numeracy", *Paper presented at the New Zealand Association of Researchers in Education Conference*, pp. 6-9, available at: https://www.nzcer.org.nz/system/files/10604.pdf

Organisation for Economic Co- operation and development [OECD] (2012), *Literacy, Numeracy and Problem Solving in Technology- Rich Environments: Framework for the OECD Survey of Adult Skills*, OECD publishing, available at: https://www.oecd-ilibrary.org/education/literacy-numeracy-and-problem-solving-in-technology-rich-environments_9789264128859-en

Phillips, I. (2002), "History and mathematics or history with mathematics: does it add up?", *Teaching History*, Vol. 107, pp. 35-40, available at: https://search.proquest.com/docview/213373442?accountid=14647

Smith, P.L. and Ragan, T.J. (2005), *Instructional Design*, Wiley, New York.

Steen, L.A. (2001), "Mathematics and numeracy: two literacies, one language", *Journal of the Singapore Association of Mathematics Educators*, Vol. 6 No. 1, pp. 10-16, available at: http://www.stolaf.edu/people/steen/Papers/numeracy.html

The Crowther Report (1959), *A Report of the Central Advisory Council for Education (England)*, HMSO, Crowther Report, available at: http://www.educationengland.org.uk/documents/crowther/crowther1959-1.html

Trevisan, M.S., Davis, D.C., Calkins, D.E. and Gentili, K.L. (2013), "Designing sound scoring criteria for assessing student performance", *Journal of Engineering Education*, Vol. 88 No. 1, pp. 79-84, doi: 10.1002/j.2168-9830.1999.tb00415.x.

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