Pre-Service Primary School Teachers' Understanding of the Meaning of 'Capacity' in the Australian Curriculum: Mathematics

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Ambiguity of language can form a barrier to understanding mathematical concepts. The word 'capacity' is problematic as it holds a variety of meanings and might not be understood in school mathematics, to be an aspect of volume. We investigated pre-service primary school teachers' interpretations of 'capacity' when given the definitions of 'volume' and 'capacity' provided in the Australian Curriculum: Mathematics. Of the 72 participants, 20 appeared to hold the conception that the volume of a liquid is its capacity. We suggest reducing ambiguity by defining 'capacity' more clearly or by excluding this word from formal mathematics terminology.

In mathematics education, a distinction is commonly made between 'mathematical language' which is precise, explicit and averse to ambiguity, and 'everyday language' which is informal and has a largely implicit meaning based on the context in which it is used (Barwell, 2005). Alternative conceptions can arise when a term that students already understand informally, differs from the formal mathematical term defined in a mathematics curriculum (Avgerinos & Remoundou, 2021). The term 'capacity' is one such term.

Capacity has multiple meanings. It comes from an old French word, *capacité,* which means 'ability' in a legal, moral, or intellectual sense. In a physical context it means "ability to contain; size, extent" (Harper, 2024). *Capacity* can be understood as an ability to store electricity or an ability to hold either a volume, or a weight, or a number of people or items, depending on the context (Ho & McMaster, 2019). In the Australian Curriculum: Mathematics (AC:M), *capacity* is defined as "the amount a container will hold. It is often in relation to the volume of fluids. Units of capacity (volume of fluids or gases) include litres (L) and millilitres (mL)" (Australian Curriculum Assessment and Reporting Authority [ACARA], 2022). In this definition, the word 'amount' could mean a volume or a weight and the word 'often' could imply that *capacity* is not always a volume. However, the units of litres (L) and millilitres (mL) mentioned in the definition imply that *capacity* is an attribute of fluids. This alternative conception has significant implications for understandings in science where students learn about states of matter (McMaster et al., 2021). Most Australian primary school teachers teach both mathematics and science. If pre-service teachers (PSTs) are confused by the meaning of *capacity*, it follows that their students will be confused.

The exploratory research documented in this paper focuses on the question: What do pre-service primary school teachers understand to be the meaning of *capacity*, when given the definitions provided in the Australian Curriculum: Mathematics?

Literature Review

There is lack of prior research concerning teachers' understanding of the term capacity when it is formalised in a mathematics curriculum. There is however, a large body of research on alternative conceptions and how such conceptions develop (e.g., Vosniadou, 2013).

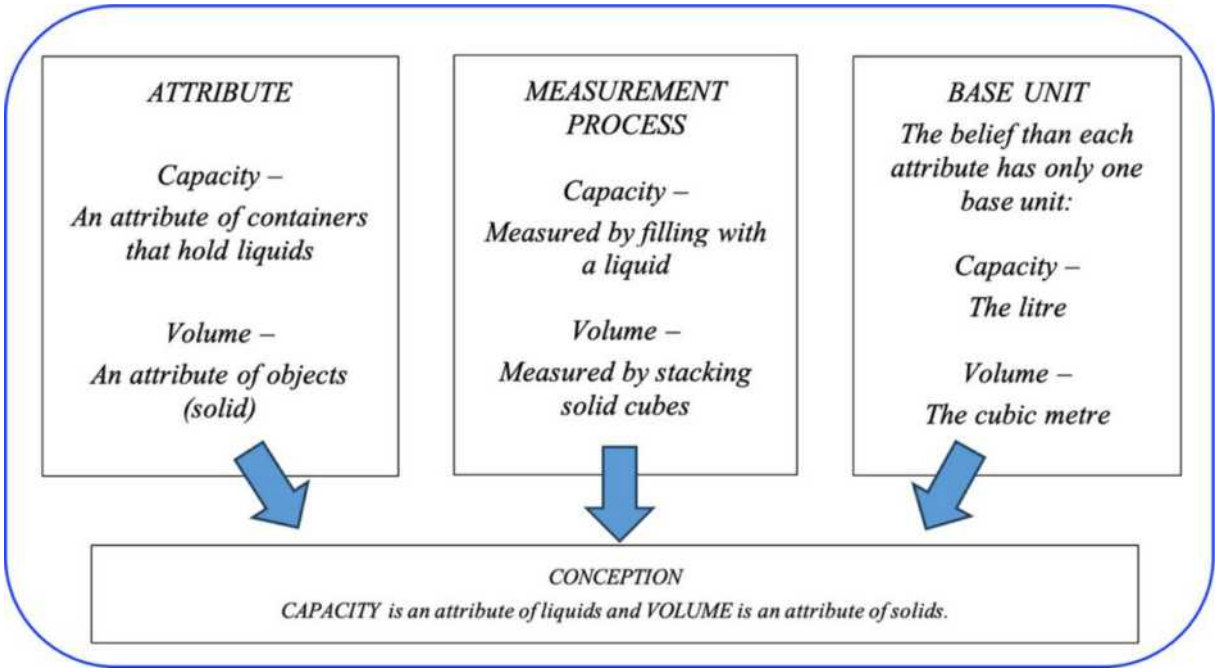
Resnick (1991) argues that all knowledge is situated, meaning that it reflects the particular conditions in which it was produced. Hence, to understand an alternative conception, the context in which that conception developed needs to be recognised. Hallden et al. (2013) present a theory of conceptual change which accounts for context. They propose a 'compounded model'

(2024). In J. Višňovská, E. Ross, & S. Getenet (Eds.), *Surfing the waves of mathematics education. Proceedings of the 46th annual conference of the Mathematics Education Research Group of Australasia* (pp. 407–414). Gold Coast: MERGA.

to describe the way in which individuals create a coherence of meaning from a collection of two different sources of information. Their model illustrates the piecing together of contrasting information to create a coherent whole that makes sense to the individual. Based on the theory of Hallden et al. (2013), we hypothesise a synthesis of the three sources of information and experiences that could account for the conception that capacity is an attribute of liquids while volume is an attribute of solids. These sources are: the definition of the attribute, the experience of measuring the attribute, and the base unit of the attribute. They are illustrated in Figure 1 and detailed in this literature review.

Figure 1

Information and Experiences Compounding to Form the Conception that Capacity is an Attribute of Liquids and Volume is an Attribute of Solids



When Harrison (1987) questioned young children (four to seven-year-olds) about the capacity of containers, they thought about how much a container *was* holding rather than what it *will* hold or *could* hold. Irrespective of the size of the container, children thought its *capacity* was how full it was. On reflection, Harrison (1987) thought their concentration on the liquid (the filled space) rather than the space inside the container, was logical. People naturally tend to notice first, the fullness of a container: how close it is to reaching its capacity.

The Measurement Process

In the AC:M, the process specified for measuring capacity is to fill containers with pourable materials such as water. In Year 1 it is suggested that they "pour sand/rice/water from one container to another to compare and order the capacity of 3 or more containers" (ACARA, 2022). This process is different from the process suggested in Year 7 for measuring the volume of a rectangular prism, namely stacking unit cubes in rows, columns and layers.

In Ho and McMaster's (2019) study, six 11- and 12-year-old students were asked during a task-based interview, how they would find the volume of a plastic box and then how they would find its capacity. Five of these students, having initially been confused about the difference between volume and capacity, became open to believing that the capacity of the container meant its volume in this context. However, the remaining student held firmly to the conception that if the volume inside the box was measured with unit cubes, this was the volume of the box and if the same space was measured with water, this was the capacity of the water. The conception

that capacity is the volume of a liquid can be seen in a teacher's annotations of student work samples for Year 3 on the website housing the AC:M (ACARA, 2022).

The Base Unit

Another contributing factor could be the belief that in our metric system, each measurement attribute has only one base unit. In the International System of Units (known as the SI system), the metre is the only base unit for length, and the cubic metre is derived from this base unit. However, there are two official units that can be used to quantify a volume in Australia's metric system—the cubic metre and the litre (Australian Government, 2024). People who believe the cubic metre is the only metric unit for the volume of a solid, could believe that the litre is the only metric unit for the volume of a liquid. There are mathematics education textbooks for pre-service teachers that reinforce this conception, possibly due to the writers' interpretation of the AC:M. Tables in Cotton et al., (2023, p. 229) and Reys et al. (2023, p. 611) for example, do not list the litre as a metric unit of *volume*, but as a metric unit of *capacity*.

Method

The method was based on the premise of Hallden et al. (2013) that learners' conceptions can be understood by examining their responses to constructed contexts. The 'learners' in this study were primary school pre-service teachers (PSTs). For them, the context of responding to a student's statement and marking a question is particularly relevant to their future career. An online questionnaire was used because it enabled anonymity and a larger sample size than would be possible by interviewing participants. The research was conducted early in 2020.

The Participants

The study involved 72 PSTs at a metropolitan university which has a relatively high entry requirement into their initial teacher education programs for teaching in primary schools: a four-year Bachelor of Education (Primary) program (BEd) and a two-year post-graduate Master of Teaching (Primary) program (MTeach). The program and year level of the 72 participants is shown in Table 1. The BEd Year 4 cohort had attended a lecture and a tutorial class the previous semester, in which they were explicitly taught the meanings of *volume* and *capacity* in the mathematics curriculum. As part of the unit of study, they also experienced teaching the topic 'Volume and Capacity' to a small group of students at a local primary school. The other PSTs had not yet encountered this topic in their program, however four PSTs in BEd Year 3 (PSTs 47, 48, 49, 50) and four in MTeach Year 2 (PSTs 30, 31, 32, 33) had either taught the topic or seen it being taught, most likely during their profession experience placement.

Table 1

Participants in Each Cohort with Teaching Experience on the Topic of 'Volume and Capacity'

Program and year level	Number of participants	Number with teaching experience	Individual labels
MTeach (Primary) Year 1	25	0	PST1 to PST25
MTeach (Primary) Year 2	7	4	PST26 to PST32
BEd (Primary) Year 1	4	0	PST33 to PST36
BEd (Primary) Year 2	3	0	PST37 to PST39
BEd (Primary) Year 3	10	4	PST40 to PST49
BEd (Primary) Year 4	23	23	PST50 to PST72
Total	72	31	

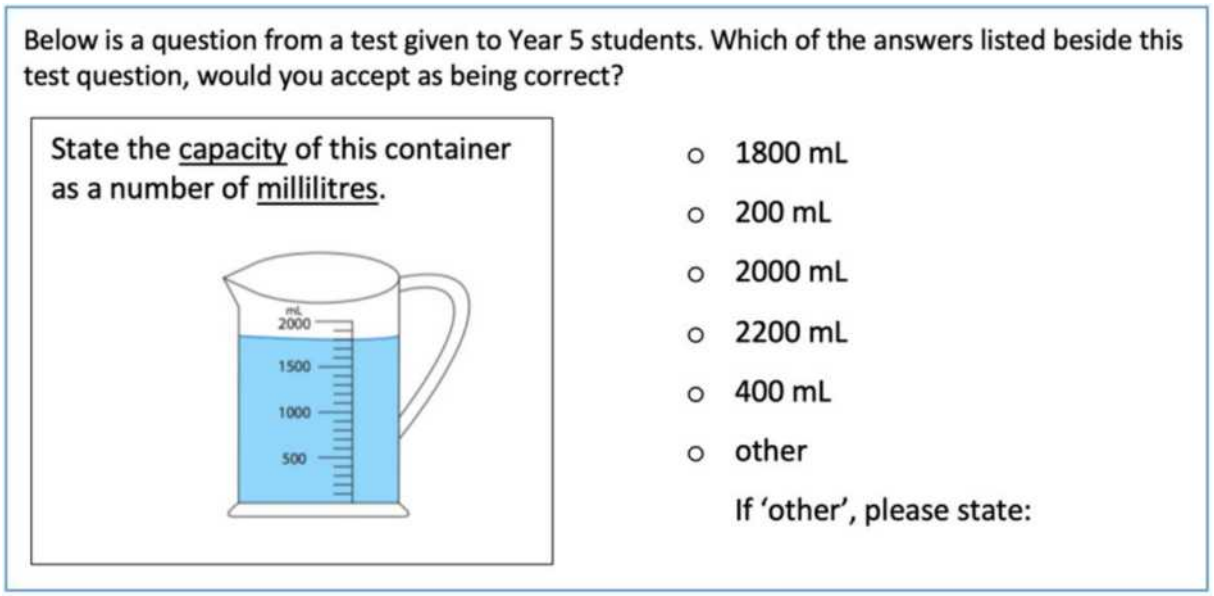
The Questionnaire

The online questionnaire began by providing participants with the definitions of *volume* and *capacity* stated in the AC:M (version 8.4) and inviting them to read then state these definitions in their own words (Item 1). These definitions were the same as those in the current AC:M (version 9). *Volume* was defined as "a measure of the space enclosed by the solid" and *capacity* was defined as "a term that describes how much a container will hold. It is used in reference to the volume of fluids or gases and is measured in units such as litres or millilitres."

Item 2 was designed to obtain quantitative data concerning the number of PSTs' holding the conception that the volume of a liquid is its capacity, and qualitative data from those PSTs who gave an extended response. The PSTs were asked to state whether they would agree with a student who says, "Objects have volume and liquids have capacity" (Item 2a). It was expected that PSTs holding the alternative conception would agree with the student. To confirm whether they held this conception, they were given Item 2b about which capacity of a jug (Figure 2) they would accept as being correct. This question was sourced from a commercial test for Year 5 students and made a multiple-choice question. If a PST held the alternative conception, they were expected to select 1800 mL as the correct answer.

Figure 2

Item 2b) From the Questionnaire



A final item (Item 3) asked PSTs if they had any concerns about the wording of the curriculum definitions. This item was to yield additional qualitative data and possibly clarify earlier responses.

Analysis of the Data

The data were analysed to determine the extent to which the PSTs held the conception that the volume of a liquid is its *capacity*. Data obtained from those students who gave extended responses to Item 2 and those who responded to the Items 1 and 3, were further analysed to determine possible reasons for their conception and the nature of their concerns about the curriculum definitions of *volume* and *capacity* in the AC:M.

Responses to the statement "Objects have volume and liquids have capacity" were sorted into three categories: agree (a response of 'yes', 'correct', or 'agree'), disagree (a response of 'no', 'incorrect' or 'disagree') and unsure (a response of 'I don't know' or something similar). Some responses raised ambiguities that were not envisaged. These were discussed by the two

researchers until a common understanding was reached. For example, one PST responded by saying "Objects have volume, and they can hold a given capacity of liquid". It was decided that because they referred to 'capacity of liquid', they agree with the conception that liquids 'have capacity'. Responses were also coded as 'agree' if they said objects *also* 'have capacity' because this implies that they think liquids 'have capacity' e.g., "Objects can have capacity too" (PST39).

Responses in which PSTs said they 'partially agree' with the statement were coded as 'disagree', because it was assumed that by 'partially agree' they meant that the first half of the statement ("objects have volume") is correct and the second half ("liquids have capacity") is incorrect.

Regarding the capacity of the jug (Figure 2), if a PST judged 1800 mL to be correct, they were deemed to hold the conception that *capacity* means the volume of a liquid. Using the syllabus definition of *capacity*, every multiple-choice answer could be considered to be correct except an answer of 1800 mL. If the capacity of the jug means the volume to the top of the scale (its nominal capacity) the answer is 2000 mL. If what the jug 'will hold' is interpreted to mean the available space, 200 mL (2000 mL − 1800 mL) is another correct answer. If the capacity of the jug means its brimful capacity, the answers of 2200 mL and 400 mL (2200 mL − 1800 mL) are correct. Students choosing 'other' and stating an answer were classified as correct if they explained that the brimful capacity may not be exactly 2200 mL.

Results

Restating the Definitions

Of the 72 participants, 41 stated the definitions in their own words. Most explained how *volume* and *capacity* were different. A typical response was, "The volume of an object or substance is the amount of space it takes up, whereas capacity is the amount a container can hold". No-one referred to *capacity* as a volume, however one participant said "Volume and capacity are basically the same thing" (PST9) and another referred to both volume and capacity as space, "Volume is the space that something takes up, and capacity is the amount of space that is within a container" (PST71).

Three people defined *volume* to be an attribute of solids and *capacity* to be an attribute of liquids (PSTs 20, 21, 25), and three others thought *capacity* was how much a container "has in it" or "is holding" rather than how much it "will hold" (PSTs 5, 30, 48). These people also thought 1800 mL was the correct answer for the capacity of the jug in Figure 2, indicating that they held the conception that the volume of a liquid is its capacity.

Agreeing or Disagreeing with a Student Statement

Table 2 shows that a total of 30 participants (42%) agreed to the statement, "Objects have volume and liquids have capacity". Of the 72 participants, 17 gave an extended response, thereby providing insight as to why they and possibly other participants, chose to agree or disagree with the statement.

An extended response by a participant who agreed with the statement was "Objects have volume, and they can hold a given capacity of liquid" (PST23). One participant said they only agreed because they had just read the curriculum definitions, "I would have said the opposite until I read the description above" (PST20).

The six people who, in an earlier response had defined *capacity* as the volume of a liquid or as how much a container 'is holding', all agreed with the statement.

Three responses were classified as 'unsure'. One person wrote that they "would ask the student to elaborate about what they mean by each thing 'having' something" (PST64). Another wrote that "Objects measure volume and liquids measure capacity" (PST70) presumably

confusing 'having' an attribute with measuring an attribute. The remaining 39 people disagreed with the statement. Some of their extended responses were:

- Objects can have a capacity. Liquids can be used to measure this capacity (PST43);
- Liquid is a means of finding the capacity (PST68);
- Liquids do not have capacity. It is the container that holds them that has capacity (PST71).

Marking Answers to a Question about the Capacity of a Jug

There are several correct answers to the question about the capacity of the jug (Item 2b). Fifteen people mentioned more than one answer. Almost half of all participants (35 people) said they would mark 1800 mL (the volume of the liquid) as correct, 25 would mark 2000 mL (the nominal capacity) as correct and 21 people would mark 2200 mL (the brimful capacity) as correct. Only one person included 200 mL or 400 mL as answers they thought were correct. This person also included 1800 mL as a correct answer. Altogether, three people included both 1800 mL and 2000 mL as correct answers, presumably thinking that both a container and a liquid can 'have capacity'.

Relationships Between Pre-Service Teacher Responses

The researchers envisaged that people who would mark 1800 mL as correct, held the alternative conception that *capacity* is the volume of a liquid, and would therefore agree with the statement that liquids 'have capacity'. The data in Table 2 shows that although they were twice as likely to agree that liquids have capacity compared to those who did not accept 1800 mL as correct (28% compared to 14%), they were still almost as likely to disagree or be unsure (23%) as to agree (28%) with the statement about liquids 'having capacity' (see Table 2).

Table 2

Responses to Item 2a) From the Questionnaire

	Agree (*n=72*)	**Disagree/unsure (*n=72*)**	**Total (*n=72*)**
1800 mL is not correct	10 (14%)	25 (34%)	35 (49%)
1800 mL is correct	20 (28%)	17 (23%)	37 (51%)
Total	30 (42%)	42 (58%)	72 (100%)

The Impact of Instruction

Only the BEd Year 4 cohort had received instruction on teaching students about 'Volume and Capacity' at the time when the survey was conducted. Table 3 shows a comparison between the responses of these PSTs and the remaining 49 PSTs.

Table 3

Responses of Pre-Service Teachers who had or had not yet Received Instruction About the Meaning of Capacity

Responses	**Before instruction (*n=49*)**	**After instruction (*n=23*)**
Agree that liquids have capacity	24 (49%)	6 (26%)
Would mark 1800 mL as correct	25 (51%)	12 (52%)
Both the above responses	11 (22%)	3 (13%)

Although students having received instruction were only about half as likely to agree that liquids 'have capacity', they were just as likely as others to see the level of water shown in the jug as its *capacity*.

Concerns About the Wording of the Curriculum Definitions

Only 31 PSTs responded to the final question of whether they had concerns regarding the curriculum definitions. Four people wrote 'no', three wrote 'not yet' and 17 wrote down their concerns. Most of those who expressed their concerns about the wording of the definitions of *capacity* and *volume* had had experience teaching the topic of 'Volume and Capacity'. Their main concern was the confusing nature of the terminology. Based on their experience, one wrote "The terminology can be confusing, so explicitly defining the difference between the two would be useful for younger students. Also emphasising that measuring capacity is more for real-world uses rather than volume." (PST46). A PST who had not yet taught the topic wrote "They are super confusing, I don't really understand the difference, and currently wouldn't feel comfortable teaching the difference." (PST45). Several PSTs thought the reason why the terms are so confusing, is that they are so similar. One wrote "I just generally don't understand why capacity exists" (PST69). Another thought that because they are so similar "it doesn't seem necessary to use both terms" (PST63). Further suggestions for making the topic less confusing were to begin the topic by teaching what *volume* is, using both liquid and solid contexts (PST66, PST69) and to only use *capacity* informally in real-world contexts (PST46, PST72).

Discussion and Conclusion

The conception that *capacity* is an attribute of liquids and *volume* is an attribute of solids, was prevalent amongst the PSTs who participated in the study, with 28% both agreeing with a statement that liquids 'have capacity' and believing that the liquid a container 'is holding' is the capacity (Items 2a and 2b), a conception reported by Harrison (1987).

It was surprising that about half of all the participants appeared to hold the view that the level of the water in the jug (Figure 2) was its capacity, including many who disagreed that liquids 'have capacity'. This could be because their eyes were immediately drawn to the visual reading of a scale rather than the wording of the question. By placing this item after inviting participants to read and comment on the curriculum definitions, and by underlining the word *capacity*, the researchers had hoped misreading of the question would be minimised.

Another reason for PTSs incorrectly answering Item 2b, while apparently knowing that liquids do not 'have capacity' (Item 2a) could be their misunderstanding of what 'having' means. Two PSTs mentioned the confusion this wording caused them. The statement could have also been misinterpreted by others who responded without giving a reason for agreeing or disagreeing. Clearer wording for Item 2a might be, "Volume is an attribute of solids and capacity is an attribute of liquids". It could have also been clearer if the first half of the statement was excluded because it makes the whole statement partially correct.

Another interesting finding was that some PSTs appeared to believe that the word *capacity* can be used in relation to both containers and liquids. The three participants who accepted both 1800 mL (the volume of water in the jug) and 2000 mL (the nominal capacity of the jug) to be correct answers, would fit in this category. One of the elaborations in the AC:M (Year 3) suggests that students "measure out different capacities of liquid" (ACARA, 2022).

Despite the limited number of participants and participants not being interviewed to clarify the meaning of their responses, this exploratory research suggests that there is considerable confusion amongst PSTs about the meaning of the word *capacity* in the AC:M. If these PSTs are confused, it follows that their future students will be confused. If *capacity* is only an attribute of containers, this needs to be stated clearly in the curriculum and emphasised by teachers. It could be helpful for teachers to use the term *internal volume* of a container as this is what is probably meant by *capacity*, rather than a container's nominal capacity or brimful capacity. Another possibility (one suggested by some of the PSTs) is to formally use the word *volume* and only use *capacity* informally when the context makes its meaning clear.

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