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MANUSCRIPT

# Assessing students' understanding of time concepts in Years 3 and 4: insights from the development and use of a one-to-one task-based interview

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## Abstract

Time is an important but complex area of learning for students in the primary years. This study sought to develop a tool which would provide a clear picture of students' understanding of what constitutes time and how time is related to clock and calendar use. Four major components of time, Awareness of time, Succession, Duration, and Measurement of time, with related key ideas, formed the basis for a Framework for the Learning and Teaching of Time. This Framework underpinned the development of a 69-item, one-to-one task-based interview to assess students' understanding of time. Data from interviews of Year 3 and 4 students gave a clear picture of how they experienced the mathematics of time. The range of scores across all assessed areas of the Framework revealed a considerable spread of students' understandings of time concepts. This paper focuses on the development of the Framework and interview, the interview data, and the general benefits of the use of the task-based assessment interview in assessing the mathematical understanding and thinking of children regarding time.

**Keywords** Time · Task-based interview · Assessment · Framework · Learning · Primary mathematics

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## Introduction

As a concept, time is intangible because it does not have physical attributes that can be experienced through sound, smell, sight, and touch. Nevertheless, time plays an important role in our lives, directing us constantly throughout the day and night. The complexity of time is demonstrated by its definitions and myriad linkages. Time is described by Friedman (2011) as "recurrent sequences of events, natural and conventional time patterns, invariant causal sequences, logical relations between succession and duration, the past-present-future distinction" (p. 398). Time is linked to space, distance, and speed (Casasanto et al., 2010; Piaget, 1969), and is associated with world time and personal time (Fraisse, 1984). Its understanding has engaged the likes of Aristotle, Newton, Einstein, and Hawking who have made critical contributions to time in the universe (Barnett, 1998; Hawking, 1988). An understanding of divisions of time and temporal patterns allows adults to anticipate future events (Friedman, 2000; Hudson & Mayhew, 2011) and to have memories of times past (Friedman, 1991; Hudson & Mayhew, 2011). An understanding of the past and the future can be challenging for many children as these concepts of time develop over many years (Friedman, 1977).

Our use of time has changed over the centuries and continues to evolve. As occurred in the past, time is measured according to natural phenomena such as the day and the year, but our need to measure time more accurately has seen the introduction of units of time to measure time segments from the very small, nanoseconds and milliseconds, to the very large, millennia, eons, and eras (Barnett, 1998). Common time-measuring tools in use today are the calendar, which is used to measure and record the time the Earth takes to revolve around the Sun, and the clock, which is used to measure the time the Earth takes to rotate once on its axis. As the Earth spins on its axis, a clock is used to measure the duration of time that has elapsed from a given starting point or zero. Clocks in common use in schools, households, and businesses measure the elapsed time in hours, minutes, and seconds. Using this type of clock, one complete rotation of the Earth is calculated to be 24 h. To differentiate between times that appear the same, we add a.m. (ante meridiem) to indicate times from midnight to 11:59am, and p.m. (post meridiem) for the second 12-h period from midday to 11:59 pm. More sophisticated clocks can measure time in fractions of a second and are used for more precise time measurement such as international sporting events.

As the Earth revolves around the Sun, we experience seasons, and as the Earth rotates, day and night occur. Calendars are a measure of the days in a year, the time taken for the Earth to revolve around the Sun. As the Earth's revolution is approximately 365 ¼ days, the extra one-quarter days are added together every four years giving us the extra day in a Leap Year. All the above time measurements are learnt ideas, although with foundations in observations of nature.

Time is a part of everyone's life every day. Northcote and McIntosh (1999) and Northcote and Marshall (2016) investigated the mathematics used by Australian adults in their everyday, non-occupational lives. Their studies revealed that calculations of time were the most common context for calculation. Time calculations comprised 25% of all calculations in the 1999 study, rising to 30% in the 2016 study.

The *Australian Curriculum: Mathematics* (*AC:M*, hereafter) lists the learning of time under the Measurement and Geometry strand with a strong focus on students learning to operate with clocks and calendars (Australian Curriculum Assessment and Reporting Authority (ACARA, 2022). However, the literature suggests that the teaching of time should be wider than this, including a broad range of experiences (Casasanto et al., 2010; Kamii & Long, 2003; Piaget, 1969) and including key aspects of time such as duration and succession (Fraisse, 1984; Vakali, 1991) as well as psychological time (Friedman, 1978; Vakali, 1991). Psychological time is an individual's perception of time. For example, an individual may perceive an interesting event to take less time than a dull or boring event, despite the two events having the same duration.

Friedman and Laycock (1989) stated that clock knowledge not only requires the ability to read the time from the clock face and to operate on these times but also requires an understanding of where a time occurs within the day and what activities might be happening. Furthermore, children may be able to read the dials on an analogue timepiece or the numbers on a digital timepiece but still have difficulty in understanding the concept of time. Further evidence that children experience difficulty with the concept of time is seen in the Australian NAPLAN (National Assessment Program – Literacy and Numeracy) data. Results from 2008 to 2021 indicate that students in Year 3 had difficulty reading times to the quarter hour, comparing times on digital and analogue clocks and adding days and years to a given calendar date. Year 5 students were challenged when asked to solve problems involving hours and minutes and calendar problems involving the addition of days and weeks to a given date. Even students in Year 7, the first year of secondary school in the state of Victoria, Australia, where the study took place, demonstrated a lack of understanding of time comparison such as time intervals, time zones, analogue and digital conversion, minutes to seconds, and a.m. to p.m. This would indicate a lack of alignment between curriculum expectations and student learning.

Despite the importance of time, the necessity for including it in the curriculum, and the contribution of scholars to our understanding of concepts of time and its development, there is a paucity of research on the learning and teaching of time in the primary school years relative to other mathematics curriculum topics (Burny et al., 2009; Earnest, 2017; Friedman & Laycock, 1989; Kamii & Russell, 2012). The study reported in this paper contributes to efforts to address that paucity of research.

This paper focuses on the development of the Framework, the development of a one-to-one task-based student interview, results of the first round of interviews, the implications of these data, and the general benefits of the use of the task-based assessment interview in researching the mathematical understanding and thinking of young children.

## A theoretical framework for the learning and teaching of time

Studies into children's understanding of time have principally focussed on the psychology and development of temporal relations unrelated to units of time such as the hour and minute (Earnest, 2017). Researchers have been interested in children's understanding of the passage of time and the language of time (Ames, 1946; Friedman, 1978, 2000; Friedman & Laycock, 1989), with few studies investigating how children learn to measure time and to accurately read clocks and calendars. Articles in teacher journals that relate to time tend to focus on giving teachers ideas and activities to assist children to learn to read the time on the clock face, with few activities to develop a deeper understanding of time (McMillen & Herdandez, 2008; National Council of Teachers of Mathematics, 2014).

This lack of research into the deep learning and teaching of time, and thus the perceived limitation of research underpinning the *AC:M* were instrumental in the authors' decision to develop a theoretical framework to draw together ideas underpinning the concept of time.

In what follows, the final Framework is presented, then a detailed discussion of the relevant literature which informed the identification of the major components and the key ideas within each component. The Framework for the Learning and Teaching of Time (see Fig. 1) is intended to cover key ideas that focus on important elements from the literature. These key ideas (the dot points in Fig. 1), required for a deep understanding of time, elaborate and clarify each major component. The Framework is potentially a useful guide for teachers at all year levels learning about time, given that misunderstandings occur through much of schooling. However, the 69 interview items were selected to cover each key idea and to assess what Year 3/4 students know and understand about time. Ascertaining which items are challenging for students promotes effective planning and teaching. So, although our results are specific to these year levels, we believe they will have far wider implications.

The Framework lists four major components of time with clarifying key ideas deemed to be important to developing a deep understanding: *Awareness of time* has four inherent key ideas, while *Succession*, *Duration*, and *Measurement of time* are each expanded upon with six key ideas (Thomas, 2018; Thomas et al., 2016).

### Awareness of time

Having an Awareness of time is an important foundation to developing a deep understanding of time. Key ideas are based on studies into the language children use and understand, including a knowledge of, and an understanding of, specific language related to time, understanding regular temporal patterns, identifying events on a time continuum, and one's perception of time (psychological time). The language of time has been predominate in the research literature with studies focusing on the words children use (Ames, 1946) and children's judgements of duration, speed, and distance (Levin, 1979; Siegler & Richards, 1979). Being aware of a series of ordered events allows us to measure the duration between two events (McColgan

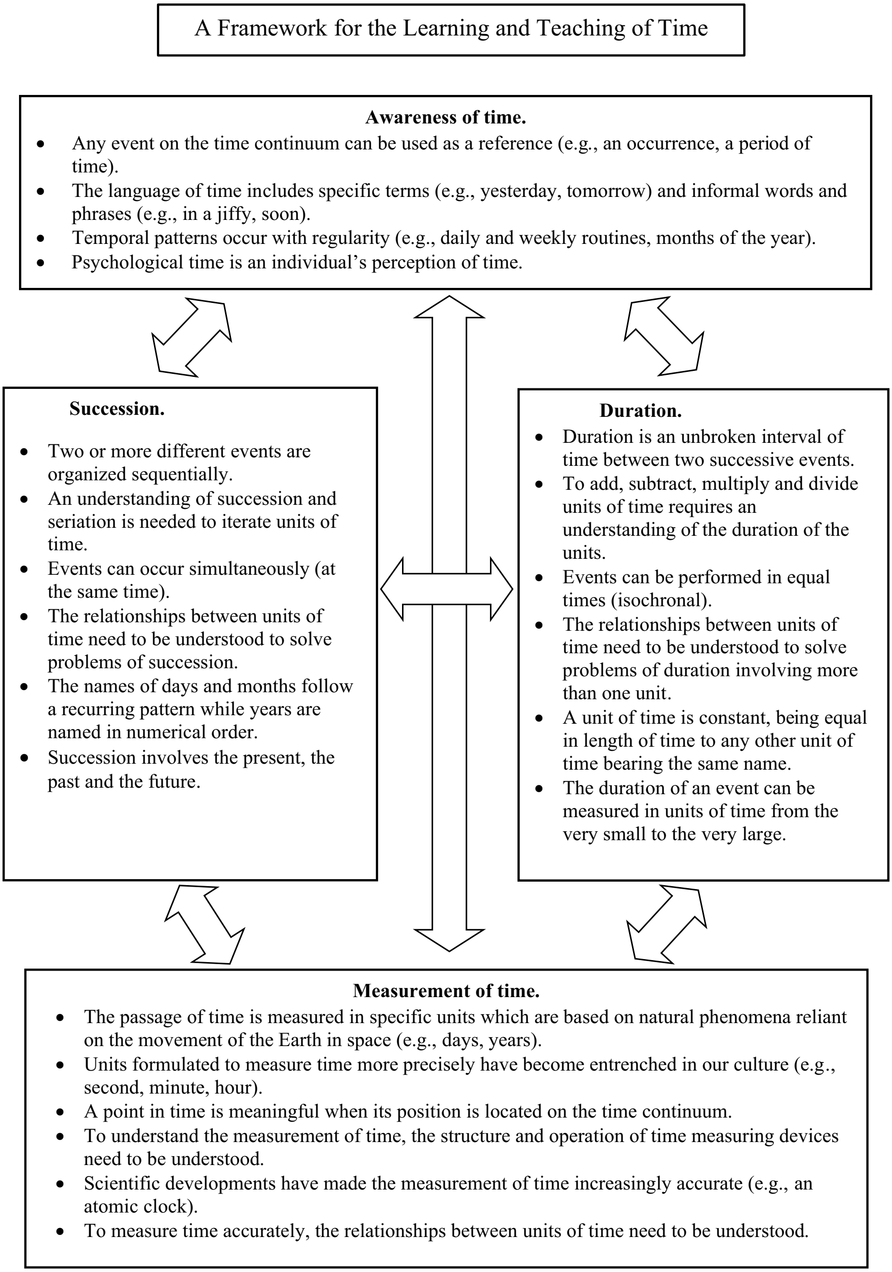


**Fig. 1** A Framework for the Learning and Teaching of Time

& McCormack, 2008). Using the first event as the zero point (Lehrer, 2003) on the time continuum, time is measured up to the second point. Any event on the time continuum can be used as a reference point.

## Succession

Succession is defined by Fraisse (1984) as the sequential ordering of two or more events that are perceived as different. Succession includes an understanding of the past, the present, and the future based on our experience of the continuous changing through which the present becomes the past. McColgan and McCormack (2008) describe our conception of time as “populated by a series of chronologically ordered events stretching from the present in two different directions, into the past and into the future” (p. 1477). Experiments conducted by Fivush and Mandler (1985) demonstrated that for children aged between four and six years, familiar events in forward order were the easiest to sequence, followed by unfamiliar events in forward order, familiar events in backward order with unfamiliar events in backward order being the most difficult to sequence. A deeper understanding of Succession requires transitive reasoning, unit iteration and the knowledge that clocks function at a constant speed (Kamii & Long, 2003). Children need to understand that a succession of smaller units can be iterated to form a larger unit. Sixty minutes form an hour, and 24 h a day. To solve problems relating to succession, students need to appreciate the important role iteration plays in sequencing and seriation. Simultaneity is a special form of succession, whereby events occur at the same time.

Succession and Duration are both important to our understanding of temporal qualities (Fraisse, 1984; Levin, 1977; Piaget, 1969). Measurement of days, months, and years are recorded in successive order. The reading of clocks and calendars requires an understanding of succession and duration.

## Duration

We view time as being on a continuum with all events placed in order. Duration is the unbroken interval of time between two separate events (Friedman, 1978; Piaget, 1969), and cannot exist without succession (Fraisse, 1984).

Each duration requires a starting and a finishing time and is measured in universal units that maintain a constant interval of time. While the precision by which duration can be measured today is evident with one second being measured at an atomic level (Taylor & Thompson, 2008), the duration of periods of time can also be measured with simple tools such as sandglasses. A duration of time can be very short (nanoseconds which are one thousand-millionth of a second) or very long (a millennium is one thousand years) and can be measured with formal units (e.g., hours, minutes, and seconds) and informal units (e.g., “a little while”). Each formal unit has a predetermined duration which is the same whenever it occurs. The importance of understanding duration is demonstrated by *The Australian Curriculum: Mathematics* that indicates students at Level 1 compare and order objects based on duration and by Level 4, students convert between units of time when solving problems involving duration (Australian Curriculum Assessment and Reporting Authority (ACARA, 2022). To add, subtract, multiply, or divide units of time as required by the *AC:M* from Level 4 (Australian Curriculum Assessment and Reporting

Authority (ACARA, 2022) requires an understanding of the relationships between units of time. For example, when the time is written in digital form, such as 4:50, the 4 and the 50, although related mathematically, are different units (Earnest, 2017). Other elements related to an understanding of duration include simultaneity (being or happening at the same time), synchronisation (keeping time together), isochronism (performed in equal times), and seriation (arranged in order). Of course, these are very complex notions. It is not expected that students in the primary years will use these terms, but rather that practical examples of each might be experienced and understanding of each gradually developed.

## Measurement of time

Understanding that time is measured is fundamental to a knowledge of clocks and the reading of the time on the clockface. As time moves forward, it is constantly measured. What students need to know to develop a deep understanding of the measurement of time is explained by the key ideas. The earliest units used to measure time continue to be significant today. The Earth's movement in space gives us day and night, years, and seasons. Other units of time, such as the hour and the minute, are a human invention arising from scientific investigation (Earnest, 2017). On Earth, as stated earlier, we measure time as a continuum (Hawking, 1988) whereby a point in time becomes meaningful when located on this continuum. To understand that time is measured requires an understanding of the operation of time-measuring devices from simple sandglasses to more advanced clocks. Scientific developments, such as the atomic clock, have made measurement of time increasingly accurate (Taylor & Thompson, 2008).

Students need to have an Awareness of time, an understanding of Succession of time and Duration of time and be able to measure time to be fully equipped to understand, to interpret and to make use of time-measuring tools. Relationships between units of time need to be understood to solve problems involving more than one unit of time. This implies that measurement of time requires a knowledge of specific units of time, their relationship to each other and their linkage to the revolution and rotation of the Earth in space, and time-measuring tools.

## The interrelationships between the components

The major components in the Framework are linked with double-headed arrows to indicate the reciprocal connection between each one, and to emphasise that the components should be taught, not as separate entities, but linked together. Although the components can be defined separately, in the classroom the interrelationships between them become apparent as the components become usable when they are understood together. Students deepen their understanding of the complex notions embedded into the Framework over a period of time.

The Framework for the Learning and Teaching of Time is an important tool for teachers and researchers as it explains the depth of knowledge required for a deep understanding of time. It can also provide a basis for the development of assessment tasks related to the understanding of time.

### The research questions

The relevant research questions for this paper are as follows:

- What are the key components of a deep understanding of Time?
- What information about Year 3/4 students' understanding of time can be garnered from the use of a task-based assessment interview?
- What are the benefits of task-based interviews that are not present in other forms of assessment?

The first of these questions we have already addressed in the above section where we have introduced the Framework. The second question will generate much of the remainder of this paper. We will comment on the third question in a section after the results are presented.

## Method

### Background to the study

The broader study was based on a constructivist view of learning (von Glasersfeld, 1995) and design research principles (Cobb et al., 2003) and entailed an eight-lesson classroom intervention. Design research was introduced in the 1990s with two objectives: theoretical research, which would contribute to theories of learning, and an intervention which would contribute to teaching practice (Anderson & Shattuck, 2012). Collaborating with practitioners, researchers are able to extend their knowledge about innovative learning environments by addressing questions from prior research (Design-Based Research Collective, 2003). Our knowledge of the characteristics of the interventions increases as educational programs and teaching–learning strategies are systematically designed, developed, and evaluated (Plomp, 2007). Insights can be gained and practical solutions developed by conducting research in the real world (Brown, 1992; McKenney & Reeves, 2012).

The Framework for the Learning and Teaching of Time and the one-to-one, task-based interview developed to assess the key points listed under the major components were based on theoretical research. After the participating students were interviewed, data from the students' responses were collated to ascertain the key ideas of the major components of time that were the most challenging (Thomas, 2018).

The intervention in a local classroom incorporated an iterative cycle of design, test and review that focussed on improving the intervention lesson content and pedagogy. Prior to the intervention, 27 Year 3 and 4 participants were assessed using the previously mentioned 69-item interview as the major form of assessment.

## Participants

A Victorian regional city school, approximately 150 kms from Melbourne, Australia, was the venue for the collection of data from the pre-and post-intervention interviews and the eight-lesson intervention. This city was chosen because it was geographically convenient for data collection and the first author was well-known to the principal and staff. The school's mathematics curriculum was consistent with the *AC:M Version 8.4* in use at the time of the study (Australian Curriculum Assessment and Reporting Authority, 2015). Of the 30 students in one combined Year 3/4 classroom, the parents of 27 students returned signed parent consent forms and agreed for their children to become participants in the study. At the beginning of the data collection, the participants ranged in age from eight years and 10 months to 11 years and one month. According to their classroom teacher, their achievement in mathematics ranged from low to high.

## The role of a task-based, one-to-one interview in assessing student understanding of time

The use of task-based, one-to-one assessment interviews has been widely adopted by primary mathematics teachers in Australia and New Zealand (Bobis et al., 2005). This type of diagnostic assessment has been used in Victoria for children commencing primary school (Santiago et al., 2011) where such interviews have been found to be valuable resources for gathering information about the knowledge and skills children possess when they begin formal schooling (Santiago et al., 2011). Clinical interviews have been used to study knowledge structures and reasoning processes of students since the 1970s (Clement, 2000), and by the late 1990s the development and large-scale use of research-based one-to-one, task-based interviews were evident (Bobis et al., 2005). Interviewing a student as they complete a task can give teachers strong insights into the student's mathematical understanding and preferred strategies when solving problems (Clarke et al., 2011). Although one-to-one task-based interviews take time to administer, teachers' knowledge of their students, including their preferred strategies, is enhanced. In addition, teachers' own content and pedagogical content knowledge are greatly improved, as well as common misconceptions and student strategies revealed by student work on interview tasks (Clarke et al., 2011). Clarke et al. (2011) found that the use of the Early Numeracy Assessment Interview by teachers led to a greater understanding of the framework which underpinned that interview. We anticipate this could also be the case in the use of the instrument assessing student understanding of time.

The one-to-one task-based interview overcomes several inadequacies of pen and paper tests. The validity and reliability of pen and paper tests has been questioned (see, e.g., Clements & Ellerton, 1995). While written tests may be helpful in identifying concepts that are difficult for students, pen and paper tests have been shown to have limitations such as failing to detect key elements of a student's thinking and reasoning, and failing to address the reasons for the existence of misconceptions (Assad, 2015; Clement, 2000; Clements & Ellerton, 1995). Clements and Ellerton (1995) observed that although children may have a strong conceptual knowledge of a topic, they may be unable to demonstrate this knowledge during a written timed test.

On the other hand, a research-based interview, incorporating thought-provoking questions, open and closed, and a variety of engaging tasks, allows students to extend their thinking and give descriptive responses (Ginsburg, 1997). Clarke and Clarke (2004) and Ginsburg (1997) suggested questions such as "How did you work that out?", "Could you solve that another way?", and "How are these two things the same and how are they different?" can encourage students to become more reflective and analytical and less dependent on the interviewer's prompts.

## Interview instrument

At the time of the study, no evidence was found of any interview that specifically targeted the assessment of time. Hence, a one-to-one task-based interview was developed and used in this research. The Framework (see Fig. 1) was instrumental in the development of this interview.

The interview incorporated items directly related to one or more key ideas listed under the major components in the Framework. Each key idea was assessed by at least one item in the interview. This resulted in 79 items which were piloted with students from a similar school and in the same regional city as those students in the study discussed in this paper. A comprehensive review of the items and the pilot students' responses led to the final version of the interview containing 69 items. A full listing of the original 79 items and the final 69 items can be found in Thomas (2018).

The items in the one-to-one task-based interview were structured to assess the key ideas of three of the major components of the Framework for the Learning and Teaching of Time: Succession, Duration, and the Measurement of time. An Awareness of time, the fourth component, was deemed to be present in all items. As an example, items relating to morning, afternoon, and units of time relied strongly on being aware, and having an understanding, of the language of time, such as the words *morning*, *afternoon*, *hour*, and *minute*. During the pilot and the actual study, it became clear that this assumption concerning Awareness of time was well made.

Three key ideas related to Succession were each assessed by four interview items, with the other three Succession key ideas each assessed by five interview items. The Duration key ideas were each assessed by five interview items. As Measurement of time included not only reading and writing analogue and digital times, but also an understanding of units of time and the passage of time, each Measurement key idea was assessed by eight items.

At the outset of the interview, each student was informed that the interviewer wanted to find out what they had learned about time and measuring time. They could expect some easy items and some more challenging items that they may not have learned yet. Some items may make them think about time in a way that they had not done before. It was important for the students to know that the interview was not a test, and they could ask for an item prompt to be repeated if necessary for clarification, or to say "I don't know" if an item proved to be too difficult.

The following examples show the item being asked, the three categories of possible responses, and the key ideas assessed. (The scoring process is outlined in the "Data analysis" section.)

***Example 1*** *Greet the student with the appropriate greeting. "Good morning" or "Good afternoon".*

How do I know it is morning/afternoon?

- **Identifies morning as between 12 o'clock midnight (12 am) and 12 o'clock midday (12 pm) OR afternoon as after 12 o'clock midday (12 pm).**
- Provides partial information but is incomplete. (Identified morning and afternoon by an event or events which have occurred or will occur such as recess, music lesson; identifies morning as before 12 o'clock midday (12 pm); refers to am or pm but no further information is given.)
- Response does not identify whether it is morning/afternoon OR other incorrect response OR no response.

Key ideas assessed:
Two or more events are organised sequentially.
The duration of an event can be measured in units of time from the very small to the very large.
The passage of time is measured in specific units.

***Example 2*** Which of these times comes first in a day? A quarter to 8. A quarter past 8. Tell me why that time comes first.

- **Correctly states a quarter to 8 and explains the reason that this time comes first.**
- Correctly states a quarter to 8 but does not satisfactorily explain the reason that this time comes first.
- Incorrect response OR no response

Key ideas assessed:
Two or more events are organised sequentially.
To add, subtract, divide, and multiply units of time requires an understanding of the duration of the units.
To measure time accurately, the relationships between units need to be understood.

***Example 3*** *Hand the student a calendar of the current year.*

Find today's date and point to it. *When found, ask,* Tell me the full date including the day.

- **Gives the day, the date, the month and the year. (e.g., Wednesday, 20th September 2023)**
- Gives the full date with prompting
- Other incorrect response OR no response

Key ideas assessed:
Two or more events are organised sequentially,
The passage of time is measured in specific units which are based on natural phenomena.

***Example 4*** How long does it take for the hour hand to go once around the clock?

- **12 h.**
- 24 h.
- Other incorrect answer OR no response.

Key ideas assessed:
Duration is an unbroken interval of time between two successive events.
Units formulated to measure time more precisely have become entrenched in our culture.

### Data collection

Prior to the intervention, 27 Year 3 and 4 participants were assessed using the previously mentioned 69-item interview as the major form of assessment. The first author interviewed the students several weeks before the end of the school year. Each interview took between 30 and 45 min.

Data from the interviews provided important information on what these students in Years 3 and 4 knew and understood about time. The data were then analysed specifically to ascertain the focus of eight lessons. Following the intervention, all students showed statistically significant improvement, as measured by data from a second round of interviews six weeks after the lessons had finished, and a delayed assessment several weeks later (see Thomas, 2018 for information on the intervention). As indicated earlier, the data from the first round of interviews provide the focus of this paper.

### Data analysis

Each item in the one-to-one task-based interview had a range of anticipated responses. A scoring method was adapted from Clements and Ellerton (1995). All responses which demonstrated a full understanding of the item were given a score of two points, with responses which demonstrated a partial understanding of the item being awarded one point, as indicated by the pre-determined response on the interview sheet. Incorrect responses or responses that indicated no understanding were recorded in written form verbatim for analysis of the student's understanding. A zero score was given for students who gave no response to the item, who said, "I don't know," "Pass," shrugged their shoulders, or gave any other incorrect response or answer.

The scoring system used to assess the responses meant that students were given credit for having some knowledge of an item. Scores of 2, 1, and 0 enabled the interviewer to ascertain which items were understood and which were challenging. In the Examples 1–4 above, the first response was scored a "2," the second a "1," and the third a "0."

Scores were entered on a spreadsheet. Each student was listed horizontally across the top of the spreadsheet and each interview item listed vertically down the left side. Each student was given a score of 2, 1, or 0 for their response to each item with a maximum score of 138 (69 items × 2). The students' scores were tallied vertically. Strengths and weaknesses for an individual student could be determined by their result for each item.

To assess the strengths and weaknesses of the class group, scores for each item were tallied to give a total score. This was achieved by adding all the students' scores for each item. If every student scored 2 for an item, the maximum score would be 54 (27 students × 2). The interview items were listed in order from the lowest to the highest score, with the lowest scoring items to be a focus of the intervention. A score was selected as a benchmark for success. Items that scored less than 40 (75%) were deemed to be items of greatest concern for the group. Scores of 40 or less accounted for 59.4% of all the items. Tallying the scores for the students and separately for the items enabled comparisons between students and between items. The underlying purpose of making these comparisons would have been achieved if another score had been used as a benchmark.

Further evaluation of the students' understanding was achieved by listing each item along with its score under the relevant key idea or key ideas. These scores were added and converted to a percentage allowing each key idea to be compared and assessed for student understanding. Spreadsheets were compiled for all the key ideas listed under Succession, Duration, and Measurement. The number of 2, 1, and 0 scores for each item dealing with a particular key idea were added and recorded as percentages. Converting the total classroom scores to percentages gave a broad indication of the degree of difficulty of each key idea and ultimately the more challenging aspects of each major component of the Framework.

The next step was to tally the scores of the key ideas under the appropriate major component. When analysed, a clear picture could be gained of the students' strengths and weaknesses regarding the three major components: Succession, Duration, and Measurement of time.

## Results

### Student understanding of time overall

The maximum score that could be gained from demonstrating a full understanding of all 69 items of the interview was 138. The students' scores for the first interview ranged from 48 to 124. The mean score for the students was 93.4 with a median score of 99.

A score was also obtained for each item by adding all students' points for the item. Lower scored items were deemed to be more difficult for the students. The maximum score for each item was 54 (27 students × 2 points). The items' scores ranged from 6 to 54 with a mean of 36.5 and a median score of 37. Calculating a score for each item allowed comparisons to be made between items, with the lower scoring items deemed more challenging for the students than the higher scoring items.

Having more than one item to assess each key idea proved to be advantageous to gaining a deep understanding of the students' capabilities. As displayed in Table 1, the number of responses demonstrating a full understanding ranged from 3 (item 3) to 19 (item 6), indicating the need for more than one item to assess each key idea and ultimately, each major component.

### Student understanding of key ideas

All the interview items were listed under at least one key idea with tables drawn up for all the key ideas. For example, five items were chosen to assess the Duration key idea of *Duration is the unbroken interval of time between two successive events* (see Table 1). For the item *Today is Wednesday. When did Wednesday start?*, ten students scored 2, 11 students scored 1, and 6 students scored 0, thus giving a total classroom score of 31 (10 × 2) + (11 × 1) + (6 × 0).

**Table 1** Items assessing the Duration key idea "Duration is an unbroken interval of time between two successive events" with frequency of 2 s, 1 s, and 0 s and total points

| Item no | Item | Scores | | | Total |
|---|---|---|---|---|---|
| | | 2 | 1 | 0 | |
| 2 | Today is Wednesday*. When did Wednesday* start? **State the actual day you are talking to the student* | 10 | 11 | 6 | 31 |
| 3 | When will Wednesday* finish? | 3 | 13 | 11 | 19 |
| 6 | Think about recess and lunchtime. Is recess longer or shorter than lunchtime? How do you know that your recess play is shorter/longer? | 19 | 6 | 2 | 44 |
| 42 | How long does it take for the minute hand to go once around the clock? | 18 | 0 | 9 | 36 |
| 44 | How long does it take for the hour hand to go once around the clock? | 11 | 3 | 13 | 25 |
| Frequency of 2 s, 1 s, and 0 s | | 61 | 33 | 41 | 155 |
| Percentages (to the nearest whole number) | | 45 | 24 | 30 | |

The total classroom score for the next item *When will Wednesday finish?* was 19 $(3\times2)+(13\times1)+(11\times0)$.

### Student understanding of major components

Tables were constructed for each major component listing the scores for each key idea. Table 2 shows the complete assessment of all the Duration key ideas. To develop an overall comparative score for a key idea of the Framework, the scores for 2, 1, and 0 for each key idea were added and converted to percentages. Each percentage was calculated by dividing the number of responses for a particular score by the maximum possible score and multiplying the result by 100. For example, for Duration, 409 responses gained 2 points from a maximum possible score of 837 (31 items × 27 responses), a total of 49% of all the responses. Possible strengths and weaknesses could be determined by the percentage of 2 point responses for each key idea.

Looking at the individual student scores for three major components promoted a deeper appreciation of the students' knowledge of the concept of time. The maximum possible score for the Succession items was 56. Students' scores ranged from 15 to 50 with a mean score of 38.6 and a median score 50. For the Duration items, the maximum possible score was 62. Students' scores ranged from 13 to 54 with a mean score of 36.1 and a median score of 35. Measurement included many items linked to other components giving a maximum possible total of 98, with students' scores ranging from 29 to 88. The mean score was 65.7 and a median score of 66.

To ascertain the students' understanding of the major components assessed with the one-to-one task-based interview, a table was constructed showing the percentage scores of 2, 1, and 0 for Succession, Duration, and Measurement (see Table 3). The results show that achieving a deep understanding of time proved challenging

**Table 2** Interview 1 Frequencies for the key ideas under the Framework component Duration

| Duration key idea | Scores | | |
|---|---|---|---|
| | 2 | 1 | 0 |
| Duration is an unbroken interval of time between two successive events | 61 | 33 | 41 |
| To add, subtract, multiply, and divide units of time requires an understanding of the duration of the units | 103 | 11 | 21 |
| Events can be performed in equal times (isochronal) | 76 | 21 | 38 |
| The relationships between units of time need to be understood to solve problems of duration involving more than one unit | 54 | 25 | 56 |
| A unit of time is constant, being equal in length of time to any other unit of time bearing the same name | 73 | 19 | 43 |
| The duration of an event can be measured in units of time from the very small to the very large | 42 | 48 | 45 |
| Total Duration responses scoring 2, 1, and 0 | 409 | 157 | 244 |
| Total Duration responses scoring 2, 1, and 0 as a percentage (to nearest whole number) | 50 | 19 | 30 |

**Table 3** Percentage of Interview 1 responses scoring 2, 1, or 0

| Major component from the Framework | Scores | | |
|---|---|---|---|
| | 2 | 1 | 0 |
| Succession | 60 | 23 | 17 |
| Duration | 50 | 19 | 30 |
| Measurement | 59 | 16 | 25 |

for many of these students. While 59 and 60% of Measurement and Succession responses indicated a full understanding, respectively, only half of the Duration responses (50%) indicated a full understanding of the items relating to this major component. Between 16 and 23% of responses demonstrated some understanding, and 17–30% of responses demonstrated no understanding at all. So, overall, just over half of the items attracted a response which indicated a full understanding.

## Discussion

### Key findings from the interview

The data from the first round of interviews, which are the subject of this paper, demonstrated that all students participating in the study found some interview items challenging, with scores ranging from low to high across the three major components Succession, Duration, and Measurement of time. The most challenging interview items (designated by scores 40 or less) were represented in all key ideas from the three major components assessed. The difficulties identified with Succession were related to ordering events sequentially, iterating units of time, and understanding simultaneity and seriation. Challenging Duration items related to duration of time between successive events, the measuring of duration using the hands of a clock, and simultaneity and seriation. Challenging Measurement items related to the relationship between the movement of Earth in space, converting between units of time, the use of clocks and calendars to measure time, and understanding that units of time are units of measurement.

It was not surprising to discover a range in the students' understanding. The results showed two particular aspects that the authors consider as very important to a deep understanding of time but were not well understood by the students. The first was the knowledge that time is measured. A clock, like time, is constantly moving at a rate that we measure. Students are often taught to read the time on a stationary clock face with little relevance to the duration of the seconds, minutes, and hours being measured. As the hands on an analogue clock move between the minute lines and the numbers, we measure the duration of time taken to move from one position to the next. Rather than simply reading the time, students need to understand that a 12-h clock is counting the seconds, minutes, and hours from midnight to midday and from midday to midnight. The second notable gap in the students' knowledge was an understanding of how time is connected to the movement of the Earth in space. Seventy-eight percent of the students did not connect the notion of time with the Earth rotating on its axis or revolving around the

Sun, even though clocks are designed to measure how much time has elapsed in a day's rotation and calendars measure the days that occur due to our revolution around the Sun.

The interview results also demonstrated strengths in the students' knowledge. A score of 50 was gained for an item when 25 of the 27 students scored 2 for their response. Items with scores of 50–54 focused on the days of the week and months of the year, the number of seconds in a minute and minutes in an hour, sequencing events that occur within a year, and the drawing of clocks. Over 90% of the students knew the current month and year and the day's date. They could draw a digital clock and an analogue clock, although when asked to draw a time on their clock, many drew an hour time.

## The power of the one-to-one task-based interview in assessing students' understanding

Clarke et al. (2011, pp. 907-911) reported that the use of a task-based one-to-one assessment interview builds teachers' expertise in a number of ways. From this list, the benefits to the authors which were clearly evident in this study were as follows:

- A clearer, evidence-based understanding of student thinking in mathematics and what students know and can do.
- An awareness of common strategies used by students.
- An awareness of common difficulties and misconceptions present in students.
- The opportunity to use tasks from the interview as models or inspirations for developing classroom tasks.

Further, we hypothesise that someone using this interview *for the first time* might experience the following additional benefits identified by Clarke et al. (2011).

- An understood framework/growth points/typical learning trajectory for students in a given domain, in this instance time.
- Revelations about "quiet achievers" in the classroom.
- Enhanced subject matter knowledge and pedagogical content knowledge.
- Improved questioning techniques, including the opportunity to see the benefits of increased wait time.

However, further research would be necessary to confirm these hypotheses.

## The importance of the framework for the learning and teaching of time

Having a deep and broad knowledge of time enables individuals to participate fully in society. The Framework for the Learning and Teaching of Time has placed core notions that underpin a deep understanding of time into a readily understood framework. The Framework can be used by teachers in a variety of ways, including planning mathematics lessons on time, developing units of work that link into other curriculum areas, and structuring the development of assessment interviews. This

Framework has implications for curriculum planning more broadly, as well as teacher planning for particular units and lessons.

The Framework for the Learning and Teaching of Time proved to be a strong foundation on which to base the interview items. Having several items in the interview that addressed each key idea, and ultimately each major component, ensured a comprehensive assessment of student understanding of time could be achieved.

This research found the *AC:M* was lacking many of these underpinning concepts of time, and the research literature did not yet offer a research-based framework. The Framework summarised the major components of a clear understanding of time by juxtaposing the key underlying ideas of the concept of time drawing upon the works of Fraisse (1984), Friedman (2011), Kamii and Long (2003), and Vakali (1991).

## Conclusion

The present study responded to the identified paucity of research in respect of primary students' deep understanding of time concepts. The development of the Framework was an iterative process in line with design research (Cobb et al., 2003). The identification of major components of time formed the initial theory on the learning and teaching of time. The initial Framework was constructed after an extensive review of the literature to identify the major components and key ideas of time. The final Framework was the result of a further review following pilot study data collection.

The interview provided an important tool to measure student understanding of the major components and the key ideas within each component. This interview was also another step forward for both research and teaching. Used as a whole, not only did it allow the investigation of the four individual components, but it also emphasised the interdependence of these components and hence the deep understanding of time by students. An Awareness of time, although not assessed separately with the Year 3 and 4 students, was deemed to be evident in all items of the interview.

The extensive list of detailed annotated and tested items should also be a valuable resource for teachers. Although conducting the 69-item interview with all students would probably be too time-consuming for many teachers, there are at least two possible compromises. The Framework and the interview together provide teachers with an idea of the kinds of understandings which they can seek to achieve in working with their students. By using carefully chosen groups of items, teachers would be able to build their own understanding of how their students are gaining insight into the components of time, and hence the overall concept of time. Alternatively, a teacher might interview just a sample of students in the teacher's class with all items. A teacher could then take what they learned from the sample to inform both their planning and teaching of the larger group. This would complement the insights offered in this paper about students' strengths and weaknesses. In addition, by looking at the requirements for each item to score 2, 1, or 0 points respectively, teachers are alerted to the way in which full understanding might differ from partial understanding, including common misconceptions. This paper has focussed on the Framework and the interview. Advice about appropriate content and recommended pedagogies for students in the middle primary years arising from this study can be found in Thomas (2018).

## Limitations

The limitations of this study are principally connected to the selection of school and the participants. It is not known how students from other schools in the state and country, or other year levels might perform in the same situations, so generalisability to other contexts cannot be assumed.

## Further research

Further research into this area would increase our understanding of student learning of time. The literature review revealed that there has been little recent research in this area, apart from the present study. Using aspects of the one-to-one task-based interview to assess students in Years 1 and 2 as they begin to learn about time, and Years 5 and 6 who are deemed to have mastered an understanding of time would complement the results from this study, as would research into teachers' own content knowledge in this area.

**An Acknowledgment of the Passing of Dr Margaret Thomas** Dr Margaret Thomas passed away during the final production stages of this MERJ manuscript. The joint paper drew on her PhD thesis titled A matter of time: An investigation into the learning and teaching of time in the middle primary years. Following a long career as a primary teacher, Marg decided in retirement to investigate a topic which had always challenged the students she taught. She approached Andrea McDonough to supervise her study, and then Doug Clarke and Philip Clarkson progressively joined the team. Marg would travel by train from country Victoria to Melbourne every three or four weeks, and we would discuss her latest writing (morning tea provided by Marg), often followed by lunch together. Our friendship with Marg and with each other grew over time and remained strong until her passing. We were all delighted that her work was awarded the Beth Southwell Practical Implications Award for 2017 by the Mathematics Education Research Group of Australasia, and she was particularly buoyed with this publication in MERJ (by 'the team' as she called us all), at a time when her illness was causing so much discomfort. Marg's work has already influenced national curricula in Australia and New Zealand. Vale Dr Margaret Thomas.

Doug Clarke, Andrea McDonough, and Philip Clarkson

**Author contribution** All authors contributed to the study concept and design. Material preparation, data collection, and analysis were performed by Margaret Thomas. The first draft of the manuscript was written by Margaret Thomas and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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**Availability of data and material** The reader is welcome to look at all data provided in Thomas (2018), but no further data will be forthcoming.

**Code availability** Not applicable.

## Declarations

**Ethics approval and consent to participate** The research study that underpins this publication was provided by Australian Catholic University Human Research Ethics Committee (HREC), Register number

2015-82E. Permission to conduct research in Victorian government schools was granted by the Department of Education and Training, number 2015_002679. Two copies of participant information letters were sent to the school principal, the classroom teacher, the parents of the students, and the students. To participate in the study, the principal and classroom teacher were required to sign both consent forms, retaining one for their records and returning one to the researcher. The parents were also required to sign both consent forms for their children to be participants and the students were required to sign assent forms. Parents retained one copy of the consent/assent forms. Informed consent was given by all participants in the study.

**Conflict of interest** The authors declare no competing interests.



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