Time: Assessing Understanding of Core Ideas

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Although an understanding of time is crucial in our society, curriculum documents have an undue emphasis on reading time and little emphasis on core underlying ideas. Given this context, a one-to-one assessment interview, based on a new framework, was developed and administered to investigate students' understanding of core ideas undergirding the notion of time: succession, duration and measurement. This paper reports on the development and implementation of the interview and initial results for Year 3/4 students.

Time is a part of our existence. We are aware of time and we have a sense of the passing of time although we cannot see it. Time has been measured since early civilisations found ways to measure the daylight hours and the measurement of time has become more refined over the years with the advent of time measuring tools such as mechanical clocks in the Middle Ages (Barnett, 1998; Dohrn-van Rossum, 1996), and more recently, the atomic clock (Barnett, 1998; Dohrn-van Rossum, 1996; Hawking, 1988). This paper deals with students' performance on a test of crucial underlying ideas of time.

Literature and Theoretical Framework

We have identified core ideas that undergird the notion of time: *An Awareness of time*, *Succession*, *Duration*, and the *Measurement of time*, and formulated a theoretical framework based on these core ideas for the learning and teaching of time (Thomas, Clarke, McDonough & Clarkson, in review). Having *an awareness of time* includes understanding the notions of a point in time, or period of time, that can be used as a reference point, the formal and informal language of time, temporal patterns such as the cycles of daily events, months and seasons, and psychological time or our perception of time (Ames, 1946; Friedman, 1977, 1990). *Succession* is the sequential ordering of time while *duration* is the passage of time, with each *duration* requiring a starting and a finishing time (Fraisse, 1984). To understand fully what they are doing when *measuring time*, students require a knowledge of not only specific units of time and the tools with which we measure time, but also an awareness of time and an understanding of succession and duration, as indicated in the following statement by Friedman (2011):

> Although we have a single word for it, time is many things: recurrent sequences of events, natural and conventional time patterns, invariant causal sequences, logical relations between succession and duration, the past-present-future distinction, and many others. Children's adaption to time depends on a mixture of biologically based temporal abilities and general cognitive mechanisms applied to time (Friedman, 2008). Their understanding of time develops gradually from infancy through adolescence. (p. 398)

We have shown elsewhere that there is little research on teaching as well as students' understanding and learning of time: The Australian curriculum devotes little time to the topic of time, and when the topic is addressed there is an overwhelming emphasis on measuring time (Thomas et al., in review). To gain some understanding of what students

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know about time, an assessment tool was developed. In line with the notions of time presented in our theoretical framework, a one-to-one task-based interview was developed to assess Years 3 and 4 students' understanding and learning of time. The interview focussed on the core ideas of succession, duration and measurement. All questions related in one way or another to an awareness of time. By Years 3 and 4, one could assume some awareness of time that may not be evident in the earlier years of school, and hence we chose not to focus on this core idea.

While tests have been conducted in classrooms to determine knowledge of facts and skills, questions have been raised about the reliability and validity of pen and pencil short answer tests to assess mathematical understanding (Clements & Ellerton, 1995). A process approach, such as interviewing the students, identifies problem solving skills and higher order thinking strategies and allows teachers to develop a deeper understanding of students' thought processes and whether their processes use the underlying ideas of the issue being assessed (Webb, 1992). Ginsburg (2009) also suggested that interviews allow more information to be gained regarding the students' strategies and cognitive processes than can be gained by classroom observations or responses to classroom tasks. Hence through the interview process with students, teachers and researchers are able to determine whether a student has made a simple error or is lacking in conceptual knowledge, can more easily diagnose misconceptions, and are in a much better position to assess students' abilities to express mathematical knowledge verbally (Huinker, 1993).

Task-based, one-to-one assessment interviews are now widely used by mathematics teachers in Australia and New Zealand (Bobis et al., 2005). For example, one-to-one interviews in English and Mathematics, where data are entered online, are used in the state of Victoria as diagnostic assessments for children commencing primary school (Santiago, Donaldson, Herman, & Shewbridge, 2011). Santiago et al. (2011) reported that these assessments were a valuable resource for gathering information about the knowledge and skills children possess when they commence school. Thus most students in Victorian schools are quite familiar now with this form of assessment.

A good interview is supported by thought provoking questions, so researchers and teachers need to consider the type of questions to be asked. 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?", all to encourage students to become more reflective and analytical and less dependent on the interviewer's prompts. Ginsburg (1997) also listed the following points as important in developing an interview: questions should be informed by the literature and the interviewer's formal observations, include open and closed questions allowing the students to extend their thinking and give descriptive responses, include a variety of tasks, and extend students' thinking.

Methodology

The interview discussed in this paper was developed in line with the theoretical framework (Thomas et al., in review). The above notions found in the literature, suggested as important in developing one-to-one interviews, also gave guidance to its development. The interview consisted of some closed questions, (e.g. "When does am change to pm?"), some open questions (e.g. "What is something that takes a long time to do?"), and task-based activities such as the student drawing a timeline of events in a school day. Each question and task was designed to learn more about students' understanding of the phenomenon (Lodico, Spaulding, & Voegtle, 2010; Merriam, 2009; Savin-Baden & Major, 2013). While the same broad interview format was used with all children in this study, to ensure that all were asked the same questions, the protocol of the semi-structured nature of the interview allowed the interviewer to ask for more detail if required, to repeat a question, or to rephrase a question of a word or phrase was not understood.

To gain a deeper understanding of what the students know and understand about core ideas of succession, duration and the measurement of time, it was necessary to formulate questions that matched these core ideas as well as facets of each idea. This resulted in a total of 74 questions.

To ensure the questions and the language used in the interview were suitable for the age group selected, the interview was piloted with students from Years 3, 4, and 5 from a school unconnected with the main study. Piloting of the questions at this trial school allowed several versions of some questions to be trialled and enabled the first author to describe, for each question, the kinds of responses that appeared to indicate no understanding, partial understanding or full understanding of the relevant concept or skill. These descriptions were examined carefully by the research team. An analysis of student responses in the pilot study, along with a comprehensive review of each question by the authors led to the final version of the interview which was used for the main study.

To assess students' understanding, a scoring method used by Clements and Ellerton (1995) was adopted whereby for each question, students were assigned points: 0 points indicated no understanding, 1 point indicated partial understanding, and 2 points indicated full understanding. Given the points available for each question, a total of 152 was possible. The points possible for succession, duration, and measurement, were 58, 70, and 82, respectively. These do not sum to 152 because a given question could be linked to more than one element in the framework.

The following example of a question on succession is an illustration of the scoring:

Q. What year were you in Prep? [The first year of school.]

- *The correct year (Student in Year 3 = 2012, Year 4 = 2011). 2 points.*
- *A year within a year of the correct year (Year 3 = 2011 or 2013, Year 4 = 2010 or 2012.) 1 point.*
- *Not within a year of the correct year or doesn't know. 0 points.*

The 30 participants in the main study were in a combined Year 3 and 4 class in regional Victoria. The students were interviewed twice: before and after the teaching of an eight lesson intervention developed by the first author. Only data from the first interview is discussed in this paper.

Twenty seven of the 30 students in the class were interviewed (the other 3 students did not have parental permission to be interviewed by the researcher). The participants comprised 14 Year 3 students (5 girls and 9 boys) and 13 Year 4 students (6 girls and 7 boys). Year 3 and 4 students were selected for this study as the relevant literature and Australian curriculum documents indicated that the critical grades for students learning about time and formalising that learning was in the middle of the primary school years (Australian Curriculum Assessment and Reporting Authority, 2014). A benefit in focussing on Years 3 and 4, rather than younger students, was that by then it was easier to have more in-depth discussions with students concerning their understanding of time concepts and their strategies for solving time problems.

Each interview was conducted in an interview room away from the classrooms, but within close proximity of the administrative section of the school. The interview took approximately 40 minutes per student, and all interviews were audiotaped. It was explained to each student that the interview was not a regular test, their results were confidential to the research team, and pseudonyms would be used for all students. Whilst being encouraged to attempt every question, students were permitted to say “pass” if they did not know, or could not think of a response.

All questions were initially presented to each student using the language and format on the question sheet. Sometimes slight changes to the format occurred when requests were made for a question to be repeated, a word or phrase was not understood, or the interviewer needed more information. For example, the following student’s response prompted the request for more detail:

Interviewer: When does am change to pm?
Student: Twelve o’clock.
Interviewer: Can you give me more information?
Student: Twelve o’clock in the daytime.

The points for each item scored by each student were entered onto a spreadsheet. This allowed for overall total scores per student to be calculated, as well as total scores for the succession questions, the duration questions and the questions on the measurement of time. Questions that were linked to more than one core idea were added to each spreadsheet to which the question was aligned; hence as noted above a certain amount of double counting occurred. On the spreadsheet, highlighting when 0 and 1 were scored for particular items presented an overview of common difficulties and misconceptions which were to become the focus for the intervention lessons (not reported on here). Descriptive statistics arising from student performance are reported in the following section, including performance on illustrative items from each of the core ideas.

Results and Discussion

All the 27 participating students responded to all questions. The overall results from the initial data collection are provided in Table 1.

Table 1
*Interview Results (*n *= 27)*

	Total	Succession	Duration	Measurement
Maximum possible	152	58	70	82
Mean	109.6	42.8	50.2	58.86
Percentage mean	72%	74%	72%	72%
Median	111	44	52	61
Standard deviation	20.7	7.7	10.1	12.6
Range	82	37	46	45
Maximum achieved	142	54	68	76
Minimum achieved	60	17	22	31

The mean scores in Table 1 suggest that the students on this assessment interview had a reasonable grasp of the items that were in the test. Interestingly, there was little difference in overall performance between the three core ideas. It might have been anticipated that students would have scored more highly on measurement, given the emphasis it has in the curriculum, but this did not prove to be the case. There was some difference in the spread of scores shown by the standard deviations. It might have been expected for the same reason that scores for measurement might have been more closely clustered, but that was not so.

As the total score data did not meet normality requirements (Shapiro Wilk 0.947; $p = 0.003$), a Wilcoxon Signed Ranks Test was used to determine whether there were significant differences in Age or Gender, which found no significant difference by age or gender (for age: $W = 145$; $p = 0.120$; for gender: $W = 149$; $p = 0.818$).

The main purpose of the preliminary testing was to inform the planned teaching intervention (not reported on here) that would focus on the core ideas of time, which give deeper understanding of the concept, rather than concentrating in the main on measuring time. To this end some items gave added insights that would prove valuable in the subsequent teaching, but are of interest in their own right. They also illustrate the different aspects of the theoretical framework, and hence give some indication of students' understanding of key ideas that goes beyond the more general statistics reported in Table 1.

Some key items are listed below as *a* through *h*. The item, shown in italics, is followed in parentheses by the "core idea", and the percentage of students who obtained a 2 (full understanding) for this item. For comparison purposes, each item can be also found in Table 2 where the full listing of student scores for each of these eight items is shown.

Items *a*, *b*, *c* and *d* focus on individual core ideas of time: succession, duration and measurement, respectively. These items also help to clarify what we mean by each of these core ideas. However, as noted earlier, and a key part of the framework, these core ideas often appear together and in various ways are interdependent on each other. Hence some items in the interview (*e* though *h* in this list) drew on two of the core ideas. Finally item *i* is illustrative of items that drew on the three core ideas.

a. *Today's date is [state the current date]. What will be the date two years from now?* (Succession; 59% full understanding). Twenty students correctly identified the year but only 16 of the students correctly identified the full date. Students who made errors were unable to add two years to the current year or were unsure about the month and the number of the day.
b. *If you had a calculator, how would you work out how old you are in days?* (Duration; 37% full understanding). This was a challenging question for the students with 11 students unable to think of a way to solve this problem. Students who attempted the problem but were unable to solve it suggested ideas such as: adding 1=1=1=1 using the constant function on the calculator, up to the number of years, concluding it was 18; squaring their age in years, for example 9 x 9; and multiplying their age in years by some number related to time, for example 24 x 9 (24 hours in a day multiplied by 9 years).
c. *Put your head on the table for one minute. Look up when you think one minute is up. How did you work that out?* (Duration; 44% full understanding). The students enjoyed this task and were surprised if they were not exactly correct as they considered their counting method of counting seconds was accurate.
d. *Show the student an analogue clock set at a quarter to 6. Tell me what time this analogue clock shows.* (Measurement; 52% full understanding). Students sometimes confused the hour and minute hands in this position, or gave the time as a quarter to 7.
e. *Today is Wednesday. [State the current day]. When did Wednesday start?* (Succession, Duration; 52% full understanding). Approximately half of the children

were not able to identify a moment after midnight as the start of the new day. The idea of the day finishing and a new one starting immediately was a difficult concept for these students. A common error was to say that the day finished at 12 o'clock, and the new day started at one o'clock.

f. *Look at this digital clock. (Clock shows 10:27.) Imagine that this number has just changed to 7. How long will it take for this number to change to 8?* (Succession, Measurement; 89% full understanding). The students were familiar with digital clocks and were able to answer this question confidently. Interesting incorrect responses were *one second*, and *no idea*.

g. *How long does it take for the hour hand to go once around the clock?* (Duration, Measurement; 40% full understanding). As o'clock is introduced to students in their first year of school, it was interesting to note that only 11 students answered this question correctly. One erroneous response was 24 hours.

h. *We use a calendar to find the date. How can we use a calendar to measure time?* (Duration, Measurement; 11% full understanding). The idea of measuring time with a calendar was a difficult concept for students to comprehend. The students considered the calendar a tool to find the date, or check a future date such as a birthday, but not to measure time.

i. *People say that time has something to do with the rotation of the Earth. Do you know anything about that? What can you tell me?* (Succession, Duration, Measurement; 0% full understanding). Any ideas the students had about the rotation of the Earth were isolated and often erroneous facts. Although this question relates to time, this topic is in the Science curriculum for Level 4.

Table 2
Individual Scores for Selected Items

Q	Student scores																										
a	2	2	2	2	1	2	2	1	2	2	0	1	0	2	1	2	0	2	2	0	2	0	2	2	0	2	0
b	0	2	1	1	2	0	0	1	0	0	1	2	0	2	0	2	0	1	2	2	0	0	2	2	1	2	0
c	2	1	1	2	2	2	1	1	1	2	2	2	1	2	1	2	1	1	1	2	1	1	2	2	1	1	1
d	2	2	0	2	2	0	2	0	0	0	0	2	0	2	0	2	0	0	2	2	0	0	2	2	2	2	0
e	1	2	2	1	1	0	0	2	0	2	2	2	0	1	1	2	1	2	2	1	1	2	2	2	2	2	0
f	2	2	0	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2
g	2	2	0	0	2	0	1	0	2	0	0	1	0	0	2	1	1	2	2	2	2	0	2	2	0	1	0
h	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	1	1	1	2	1	1	0	0	2	0	2	0
i	1	1	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	1	0	1	0

Taken together, the responses to these illustrative key items show that the percentages of students with a full understanding of succession, duration and measurement of time are lower than desirable. Forty percent of students did not have a full understanding of the sequencing of years, and almost half of the students were unsure how the hands of the clock worked in unison to show the succession of time. Duration of time requires a starting and a finishing point, but almost half of the students were challenged when they were asked to identify the beginning of the day, and only one third of the students were able to convert one unit of duration (years) to another (days). Reading the time from clocks and calendars is a focus in the Mathematics curriculum (ACARA, 2014), so there was an expectation that many students would have a full understanding of clocks by Years 3 and 4. This did not appear to be the case, with 60% of the students being unsure how long the hour hand took to move once around the clock. It might have been expected that the results for measurement of time, would have been higher, in line with curriculum expectations.

For the complete interview, the mean percentage of students demonstrating full understanding of Succession questions was 63%, with 60% for Duration questions, and 63% for questions on Measurement of time. Overall, the mean percentage of students who gained 2 points was 64%. Percentages were calculated by dividing the number of full understanding responses for a core idea by the number of questions asked for that core idea across all the students. In general, it can be said that over one third of these students in Years 3 and 4 had little or no understanding of succession, duration, or measurement of time. The *Australian Curriculum: Mathematics* (ACARA, 2014) focusses very little on the core ideas except measurement. The above percentages, and NAPLAN results (Thomas, et al, in review) indicate that without a full understanding of all these core ideas, students understanding of the concept of time is incomplete

The interviews also demonstrated the linkage between the core ideas of succession, duration, and measurement of time. Although the percentages were lower than might be expected from a reading of curriculum expectations, the questions proved to be very useful in drawing out the students' thinking, giving them the opportunity to explain what they did know and what they did not know, and usefully informed the next stage of the main study.

Conclusions and Implications

While time is a very important aspect of our daily lives, enabling us to plan for the future and put the past into perspective, curriculum documents have tended to give an overemphasis on the reading of time measuring tools, such as the clock and the calendar. Classroom teachers are guided to focus on teaching students to read clocks to the hour, half hour, quarter hour and minute. Using a broader framework of key ideas underpinning a full understanding of time (Thomas et al., in review), an interview was created which included not only an awareness of time and the measurement of time, but also incorporated two other important core ideas; succession and duration.

Following a pilot program to refine the questions to be asked to Year 3 and 4 students, the final interview was used with 27 Year 3 and 4 students in a government school in regional Victoria. The results from the interview indicated that more than one third of the students in this classroom had no understanding or only partial understanding of succession, duration, and the measurement of time, respectively.

As an assessment instrument, the one-to-one interview proved to be quite robust. Conducting the interview with 27 students reinforced the validity of the questions. The questions were clear to the students and elicited appropriate responses that enabled us to evaluate their thinking, as the students were able to explain what they knew and could do, while at the same time revealing any difficulties including common misconceptions.

The interview data provided important insights for the development of an eight lesson intervention designed to enhance students' understanding of elements of the framework. An overview of the intervention, and the students' interview results one month after the intervention, will be given in future papers.

Implications arising from this study suggest that curriculum documents, classroom practice, and assessment need to focus on a broader view of what it means to understand time, by giving due emphasis to all underlying core ideas.

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