WHAT SCIENTIFIC CONCEPTS ARE REQUIRED TO UNDERSTAND CLIMATE CHANGE?

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ABSTRACT

A large body of international research shows that school students frequently hold misconceptions about the science of climate change. In order to investigate students' understanding of this complex topic in more detail, a concept inventory (CI) is being developed for the key scientific concepts underlying climate change. This paper reports on the first stage of this process: determining which concepts should be included. A Delphi study was conducted to consult 18 academics, researchers and high-school teachers with expertise in the topic. A literature review was also carried out to determine which concepts were cited as important for understanding climate change. The final list of concepts to be covered by the CI is a synthesis of these.

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BACKGROUND

CONTEXT FOR THIS STUDY

The research reported here is part of a larger study that aims to investigate high-school students' ideas about the concepts underlying climate change and their ability to apply this knowledge in context. It employs multiple methods: a concept inventory (CI), concept mapping and interviews. This paper describes the methods used to determine which concepts to include in the CI and the resulting list of concepts. The research reported here was granted University of Wollongong Ethics approval.

A large number of studies carried out over the past two decades have shown that school students' understanding of the science of climate change is limited and that misconceptions are common (Boyes & Stanisstreet, 2001; Fisher, 1998; Gowda, Fox, & Magelky, 1997; Hansen, 2010; Koulaidis & Christidou, 1999; Kurup, 2003; Plunkett & Skamp, 1994; Rye, Rubba, & Wiesenmayer, 1997; Schultz, 2009; Shepardson, Niyogi, Choi, & Charusombat, 2009; Taber & Taylor, 2009; Österlind, 2005). Suggested reasons for this include problems with students' knowledge of the underlying scientific concepts or in applying knowledge learned in a different context (Koulaidis & Christidou, 1999; Österlind, 2005); however this has not been directly tested. Our study aims to address this gap in the research literature.

Concept inventories (CIs) are multiple-choice assessment instruments designed to diagnose students' conceptual difficulties with a topic (Libarkin, 2008). They have been used widely in science education to examine students' ideas about a number of concepts related to a wider topic and can be administered to large participant groups. One purpose of CIs is to test the prevalence of misconceptions, as distractors are written to reflect common misconceptions. According to Richardson (2004) the first stage in CI development is deciding which concepts to test. For this purpose the author recommends the use of a Delphi study. Delphi studies have been used by Danielson (2005), Goldman et al. (2008), Gray et al. (2005), Herman et al. (2010) and Streveler et al. (2003) for this stage of CI development.

THE DELPHI METHOD

The Delphi method's basic characteristics include multiple iterations of a survey with controlled feedback, participant anonymity and after each iteration, the provision of feedback to participants in the form of statistical summaries of responses. Participants can use this feedback to revise their responses (Linstone & Turoff, 1975; Whitman, 1990). Clayton (1997) asserts that it is a "systematic, rigorous and effective methodology designed to elicit potent and valid user-friendly answers" (p. 374).

A Delphi study can be used to consult a much larger group of participants than a committee meeting, while allowing group members to consider each others' ideas and viewpoints: something that cannot be done with a survey. It also allows geographically-separated experts to participate in group decision-making without needing to attend a meeting.

METHODOLOGY
In qualitative research, credibility is derived from the use of multiple methods which enable triangulation and the consideration of multiple perspectives (Mertens, 2005). Therefore in addition to the Delphi study we reviewed the literature to determine which concepts were most commonly cited as underlying the science of climate change. The final list of concepts reported here is a synthesis of the Delphi study results and those from the literature review. These will form the basis of the CI.

REVIEW OF LITERATURE
Reports of 16 studies (Andersson & Wallin, 2000; Boon, 2009; Boyes & Stanisstreet, 1993; Boylan, 2008; Browne & Laws, 2003; Dove, 1996; Fisher, 1998; Hansen, 2010; Hobson, 2003; Keller, 2006; Koulaidis & Christidou, 1999; Rebich & Gautier, 2005; Rye et al., 1997; Schultz, 2009; Shepardson et al., 2009; Österlind, 2005) were reviewed and qualitatively analysed to determine which concepts were mentioned and by how many studies, giving rise to a ranked list of 28 concepts, the highest-ranked of which had been cited in 12 of the 16 studies reviewed.

DELPHI STUDY
Linstone and Turoff (1975) stress that there is no single definition of the Delphi study design and that the design should be dictated by the requirements of the study. We chose to limit our study to three rounds: one open-ended and two quantitative, in order to avoid undue burden on participants; however like Osborne et al. (2003) we asked participants in the quantitative rounds to comment on their reason for rating and the wording of the concept statements. In all the cases we identified where Delphi studies were used in CI development, the quantitative rounds of the Delphi studies involved Likert-ratings of concept importance, so we formatted our study in this way. However, a concept inventory can only cover around 10 concepts (Libarkin, 2008) and after the second round it became clear that we would need to prioritise the concepts. To do this we added a ranking question (Okoli & Pawlowski, 2004; Schmidt, Lyytinen, Keil, & Cule, 2001) in round three. Richardson et al. (2003) state that multiple questions testing the same concept increase the validity of the CI for each concept.

Participants
According to Cochran (1983; cited in Osborne et al. 2003) the minimum number of participants for a Delphi study is 10 and as group size increases, reliability increases. As we intended to consult a heterogeneous group we wished to recruit at least ten participants. We recruited participants by contacting members of climate research groups in Australian universities and at CSIRO, as well as high-school teachers with experience of teaching the topic. We also asked potential participants to pass the invitation on to colleagues whom they felt would be suitable to participate. Emails inviting participation in each round were sent to all those originally invited, as only 12 of the 18 people who participated identified themselves to the researchers. Participant identity was only known to the research team. Participants included twelve academics, one other researcher and three high-school teachers. Table 1 below shows the main discipline areas reported by participants in rounds 2 and 3:

Table 1: Discipline areas reported by participants

Discipline	*Round 2 (18 participants)*	*Round 3 (15 participants)*
Chemistry	2	1
Physics	3	3
Biology	3	1
Geology	3	1
Climatology	2	5
Sociology	0	3
Human geography	-	1
Earth and Environmental Science	-	1

Round one
The first round of a Delphi study should consist of one or more open-ended questions in order to minimise the likelihood of researcher influence through inadvertently limiting the scope of the study

(Haussler & Hoffmann, 2000; Linstone & Turoff, 1975; Osborne et al., 2003; Pritchard, Barrantes, & Belland, 2009). Clayton (1997) recommends supplying stimulus material to participants in this round to help participants understand the context and scope of the task. Our participants were provided with examples of learning materials currently used to teach the topic in schools: a book section (Whalley, Neville, Robertson, & Rickard, 2005) and a newspaper section (Lennon, Engel, Leigh, & Pearce, 2010) as well as a paragraph explaining the purpose of the Delphi study and the wider context of the research. The participants were asked the following two questions:

1. Please list the scientific concepts required in order to understand the learning materials provided. For each concept, please indicate which part of the learning materials it relates to, and give a brief indication of the depth of knowledge required.

2. Please evaluate the above model: describe any additional elements of the science that you feel ought to be included, or anything that could reasonably be left out, explaining your reasoning. Alternatively, you may prefer to describe the model of climate change that you feel is as simple as is scientifically acceptable, without reference to the learning materials provided or the concepts underlying them. In this case please briefly explain why you chose this approach.

Participants were asked to justify their responses, giving context and detail (Haussler & Hoffmann, 2000; Osborne et al., 2003). Only four people participated in this round; this may have been due to the fact that it took place over the New Year break. As this number was not considered sufficient and included no high-school teachers, we successfully re-invited potential participants for the second round. No literature has been identified where additional participants are sought for subsequent stages of a Delphi study: however the breadth of the method, including not running an open-ended round at all, suggests that this is acceptable practice. Responses from open-ended questions were content-analysed and categorised to form the basis for the second round. According to Osborne et al. (2003) categories or themes may be in the form of a short paragraph or a page of text and may include supporting statements or quotations. This process resulted in 24 concepts which were expressed as short paragraphs of two or three sentences.

Round two

Eighteen people including two high-school teachers participated in this round, which involved a five-point Likert-response questionnaire based on the categories generated from round one (Haussler & Hoffmann, 2000; Whitman, 1990), We asked participants to rate how important each concept was to a basic understanding of the science of climate change and used a 5-point Likert scale from “Not important at all” to “extremely important”. We also asked participants to comment on the concept statement and at the end of the survey, invited them to add any concepts they felt were missing from the list. This was important as most of the round 2 participants had not completed round 1. These data were used to refine the category statements for the third round: concept statements were re-worded and some were merged or split. This resulted in 29 concept statements.

Round three

We received fifteen responses to this survey. In round 3, statistical summaries were fed back to participants along with all comments so that each participant was aware of both the collective opinion and the arguments in favour of, or against, particular viewpoints when they re-rated the categories (Whitman, 1990). For each concept, participants were provided with the original statement, a bar plot of the Likert ratings for round 2, all participants’ comments and the revised statement or statements. They were asked to re-rate the statement and invited to comment. Finally we asked participants to rank the ten most important concepts from the list of 29. This was based on the ranking-type Delphi method (Okoli & Pawlowski, 2004; Schmidt et al., 2001), which normally asks participants to rank all the items in a rather shorted list, typically under 20 items. However, according to Dillman (2007), respondents should not be asked to rank long lists of items; also, our priority was to identify the 10 or so most important concepts. All respondents to round three completed this question.

Data analysis

Median ratings and interquartile ranges were calculated: 19 of the 29 concepts were rated 4 or 5 (“very important” or “extremely important”) so the ranking question played a key part in prioritising the concepts. Participants had been asked to rank the most important concept as “1”, the second most important as “2” etc. These numbers were reversed so the most important concepts were given “10”, the second most important, “9”, the tenth most important, “1” and all other concepts, zero. These numbers were then totalled for each concept to give a mean rating in a similar way to Schmidt et al.'s (2001) method. This gave us a ranked list which to compare the list from our literature review. It should be noted that although Likert-ratings were generally in agreement with ranking scores, this was not exclusively the case.

RESULTS

To produce a single list of concepts, the ranked lists from the literature and Delphi study were compared. Ten concepts were retained; these are shown in table 2. Concepts ranked low in both lists, or low in one list and missing from another, were discarded. Those near the top of both lists were retained. Some low-rated concepts on one list were retained because they were related to a high-rated concept on the same list and also high-rated on the other list. The concepts of the electromagnetic spectrum and interactions between electromagnetic radiation and atmospheric gases were troublesome: they were ranked high in the literature review but relatively low in the Delphi study. The electromagnetic spectrum was retained however, because of its high ranking in the literature review and because the concept of interactions between the electromagnetic spectrum and atmospheric gases, which was top-ranked in literature and relatively high-ranked in Delphi, depends on understanding it. The list was further refined by the authors. Wording was based on the Delphi study concept statements because these had been had been subject to two rounds of refinement, with modifications where necessary to reflect the findings of the literature review.

Table 2: List of conceptual statements synthesised from the Delphi study and literature review

Carbon cycle and fossil fuels: There is a fixed amount of carbon on Earth; it is cycled among the atmosphere, biosphere, soils, ocean and rocks. There are both natural and human-induced sources and sinks of greenhouse gases. Fossil fuels contain carbon that was part of living things millions of years ago. The process of burial took this carbon out of the atmosphere-ocean-biosphere cycle. Burning fossil fuels returns this carbon to the cycle.
Electromagnetic spectrum: There is Infra Red (IR) and Ultra Violet (UV) radiation beyond the visible spectrum: these are all related forms of electromagnetic energy. The Sun emits mostly visible radiation and the Earth emits mostly IR.
Interactions between greenhouse (GH) gases and electromagnetic radiation: Most of the gases that make up the atmosphere are transparent to visible light. Non-greenhouse gases are transparent to IR but greenhouse gases absorb IR: this is the cause of the greenhouse effect. GH gases allow the Sun's visible light in but absorb IR emitted by Earth. This is re-emitted in all directions - down as well as up.
Natural climate variability in the past and relationship to CO_2 levels: The climate has been different in the past (e.g. carboniferous period, ice ages) due to changes in energy emitted by the Sun, the distance between the Earth and Sun or CO2 released from volcanoes during periods of high levels of volcanism. Prehistoric climate changes correlate with changes in CO2 levels, providing evidence for the link between CO2 levels and global temperatures.
Difference between weather and climate: Weather is short-term, day-to-day climactic conditions while climate is the longer term average conditions.
Proportions of greenhouse and non-greenhouse gases in the atmosphere: Over 96% of the atmosphere consists of non-greenhouse gases. The atmosphere also contains small amounts of CO2, CH4, O3, N2O and H2O and CFCs- all of which are greenhouse gases. Water vapour is a variable component of the atmosphere and is the most abundant greenhouse gas. GH gases are not in a distinct atmospheric layer.
Radiative forcing capacity: Some greenhouse gases have more radiative forcing capacity than others, ie: a given amount of a "stronger" greenhouse gas would result in more radiative forcing than the same amount of a "weaker" greenhouse gas.
Feedback: changing one parameter can have an effect on another parameter which causes a changes in the original parameter. Feedbacks can be negative (ie: tends to return the parameter to its original value) or positive (ie: tends to drive the parameter further away from its original value) e.g. increasing CO2 raises surface temps causing more water to vaporise, which further raises temperatures.
Equilibrium of energy: there is a balance of energy into and out of the Earth / atmosphere system. A net flow of energy into or out of the Earth / atmosphere system leads to temperature change over time.
Conservation of energy: Energy can change from one form into another but the total amount of all forms of energy remains constant

DISCUSSION AND CONCLUSIONS

A significant advantage of the Delphi method for our study is the fact that it allowed participants to respond in their own time and without having to travel. This enabled the participation of 18 people -

academics from at least four universities, other researchers and high-school teachers from at least two schools - who undoubtedly would not all have been able to attend a meeting. An important outcome of the Delphi study was the refinement of concept statements made possible by participants' detailed comments. Defining the scope and boundaries of concepts determines what does, and does not need to be known about each concept: this information is vital when developing concept inventory questions. According to the Delphi participants, less needs to be known about concepts related to waves, than was first thought. There were some significant differences between the ranked lists resulting from the Delphi study and literature review, although these were able to be reconciled and a list of concepts synthesised. Both literature review and Delphi method have weaknesses. A weakness of the literature review is the impossibility of asking for clarification or checking that a statement has been understood correctly. As the literature on the Delphi method discusses, there is a fine balance to be struck between avoiding undue influence on the process and ensuring that participants have enough information understand the issue.

The low Delphi ratings given to some physics concepts was unexpected. Literature on students' ideas about climate change consistently shows conflation of climate change and ozone depletion. Typically, students describe how damage to the ozone layer allows more heat to enter the Earth's atmosphere, and discussion of heat radiated by the Earth is absent. This suggests problems with students' understanding of absorption and emission of electromagnetic radiation. However, as one participant suggests, these may have been seen not as unimportant but as only a part of the bigger picture:

> *I have selected the points that would allow one to understand the basics of climate change. I have not ranked the energy-related points - while I think these are very important and really get to the basic physics underlying climate change, they are very technical and require a bit more of a leap on the student's behalf to get the relevance.*

According to Rye et al. (1997), "efforts on the part of teachers to present 'all the details' maybe counterproductive in helping students to initially construct a clear understanding of global warming" (p. 548). One of the stated aims of the Delphi study was to determine the simplest scientifically-acceptable model of climate change and the concepts underlying this but with each round of the Delphi study, more concepts were added, and more detail suggested so arguably the study was not very successful in this regard. However, as the Delphi participants' comment above suggests, it is possible that the basic science must be connected to the wider context in order to be meaningful. This issue will be explored in future research as outlined below.

FUTURE RESEARCH

This involves development of open-ended questions addressing the concepts in the above list. These form the protocol for focus-groups of high-school students. A literature review is also being carried out to identify known misconceptions about the concepts on the list. Distractors for the concept inventory questions will be based on the findings of the focus-groups and literature review. Following piloting of the concept inventory, students will create concept maps and participate in interviews to discuss how they apply their knowledge of the concepts to explain the science of climate change.

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