A Study of Student Beliefs about the Epistemology of Science and their Relationship with Students' Personal Epistemologies

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Introduction and Background

The rationality of science is based on a central commitment to evidence as the basis of belief (Siegel, 1989). A reasonable expectation might be, therefore, that an education in science would develop students' understanding of the *epistemology of science* as it will expose them to the basis of scientific reasoning and its value. As a corollary, such an understanding might help develop their own *personal epistemology* – that is the criteria that students use for judging the value of knowledge claims. Kuhn and her co-workers, for instance, argue that, on a personal level, students need to acquire a personal epistemology which she characterizes as that of an 'evaluativist'. Such individuals are able to identify and distinguish theoretical claims from the evidence used to support them; recognise claims as potentially falsifiable; and see evidence as the means of falsification (Kuhn, Iordanou, Pease, & Wirkala, 2008). These are the elements of rational thought and such meta-knowledge is the essential foundation of skilled scientific thinking and reasoning. But what is known about students' understanding of the epistemology of science and their own personal epistemologies?

Research on students' understanding of the epistemology of science itself (as opposed to their personal epistemology) has suggested that students' knowledge and understanding is fairly limited (Driver, Leach, Millar, & Scott, 1996; Sandoval, 2003). Driver et al. concluded that students have difficulty determining the role of theories in science and the way that theories are evaluated against existing data by experimentation. In particular, scientific theories were viewed as simple descriptions of taken-for-granted facts, especially for 9-year olds. Moreover, for these students, theories were seen to be of lower epistemic status than 'facts', which were considered to be the ultimate goal of science. Such a finding stands in stark contrast to the view *within* science that 'theories are the crown of science, for in them our understanding of the world is expressed' (p. 168) (Harré, 1984). Views of scientific theories as ideas based in evidence, or as a way of modeling phenomena and predicting their behavior, were found more often in older students' responses. Sandoval and Morrison (2003) have also explored high school students' ideas of scientific theories and theory change finding: a) that scientific theories were viewed as hypotheses which are repeatedly proven; and b) the dominance of a correspondence view of science where scientific theories are thought to provide explanations of the world as it is rather than being a map of reality which has the potential to be improved.

Looked somewhat more broadly from a domain-general perspective, Hofer and Pintrich (1997) have suggested that there are four dimensions to any individuals' epistemological beliefs. These are:

- certainty of knowledge (stability)
- simplicity of knowledge (structure),
- source of knowing (authority), and
- justification for knowing (evaluation of knowledge claims).

Certainty of knowledge is something which changes over time beginning at lower levels where knowledge is certain and absolute and moving to a view where knowledge is seen as tentative and evolving and where individuals are open to new interpretations. Simplicity of knowledge is a measure of an individual's understanding of the structure of knowledge and lies on a continuum between an accumulation of facts versus a set of highly inter-related concepts. The lower-level view is to see knowledge as a set of discrete facts whilst at the higher level, knowledge becomes relative and contextual and open to interpretation. Source of knowing refers to views an individual holds about the source of epistemic authority. At lower levels it originates outside the self and resides in an external authority. The big transformation comes when the individual who was previously 'a holder of meaning becomes a maker of meaning' (Perry, 1970) (p87) and recognizes that transformation. Justification of knowing refers to the views that individuals hold about how claims to knowledge can be justified moving from dualistic beliefs where ideas are either right or wrong to an understanding that knowledge is something which requires a reasoned justification for belief.

To measure these concepts, an instrument was initially developed by Elder (2002) and then improved by Conley et al. (2004), who showed it to be internally reliable and hold a four-dimensional factor structure corresponding to these theoretical scale using confirmatory factor analysis. Data gathered from a sample of 187, fifth grade students, showed that students became more sophisticated in their beliefs about the source and certainty of knowledge in science with instruction, but that there were no reliable changes in justification.

Students' personal epistemologies, in contrast, are the means or approaches that students use for judging and evaluating claims about knowledge that they meet within their own lives – what Sandoval terms 'practical epistemologies' which he distinguishes from 'formal epistemologies' which are the ideas they hold about scientific reasoning. The latter, he argues, are hopelessly naïve (Sandoval, 2005). When it comes to assessing students' personal (or practical) epistemologies, Kuhn and her co-workers (Kuhn, 1999; Kuhn, Cheney, & Weinstock, 2000) have argued for a developmental model of students' personal epistemologies proposing that students begin life as 'absolutists' where knowledge consists of certain unequivocal facts. From here, students are thought to progress to becoming essentially relativists. This occurs when they begin to recognize that there is a subjective element to knowledge and lack any sense that there are criteria that enable some claims to be judged more valid than others. These individuals she terms 'multiplists'. The final stage is when students become 'evaluativists' and recognize that there is a need to evaluate critically the evidence provided to support claims to knowledge.

The question of interest for this research is to what extent are students' personal epistemologies related to their 'formal epistemologies'? To date, researchers in science education have seen students' personal epistemologies as only tangentially related to the central epistemological questions of science that seek to explain how we know (Kuhn, Iordanou, Pease, & Wirkala, 2008). However, their inter-relatedness is a concern for science educators. Ford (2008), for instance, argues that the predominant emphasis within science on the construction of scientific knowledge and understanding is misplaced. Rather, students need an opportunity to engage in the evaluation and critical review of knowledge claims. Such skills he sees as 'crucial resources to learning novel scientific ideas with understanding' (p.405). Only through engaging in the interplay between construction and critique which is the hallmark of scientific thinking will students:

> come to *know that* scientific knowledge is held accountable by explicit connections to nature, to *know how* to play the roles of constructor and critiquer appropriately, and to *know that* the interaction of these roles in practice yields reliable knowledge. (p.405, author's emphasis)

Moreover, if students' personal epistemologies are generally more sophisticated than their formal understanding of scientific epistemology it would suggest that their education in science has done little to capitalize on their epistemic potential. More worryingly, the presentation, either implicitly or explicitly within the context of school science of a naïve epistemology could be hindering the development of students' personal epistemology. Given that science has done more than anything else to deliver societies from the shackles of received wisdom (Collins, 2000), this would represent a profound irony.

The interrelationship between students' formal epistemology and their practical epistemologies is a focus, at least in part, of the research we are conducting for the funded project 'Talking to Learn, Learning to Talk in Science'. The primary goal is twofold. First to see whether working with schools rather than individuals would help to establish a professional learning community where the use of argumentation and a dialogic pedagogy would become a more established feature of teachers' pedagogic practice. Second, we sought to see what effect it would have on students' cognition, their understanding of the nature of science and their epistemic beliefs. To answer the latter question we have drawn on the work of Kuhn et al. to assess student's practical epistemologies, the work of Conley et al. to assess students' epistemological beliefs, and the work of Driver et al. (1996) to assess both. Our goal is based on an argument that this data may help to fill this lacuna in the literature and to answer the question of what is the relationship, if any, between students' knowledge of the epistemology of science and their personal epistemic beliefs. The central question of interest here being one of whether a better understanding of the epistemology of science is associated with a more sophisticated personal epistemology?

Methods and Design

For this work, 9 schools were recruited from the Greater London area (4 for the intervention and 5 to act as controls). The sample was purposive in that schools were selected to represent a range of socio-economic conditions. From each school, two classes of Grade 6 and two classes of Grade 8 students were selected for testing. Thus the sample consists of approximately 480, Grade 6 students and 480, Grade 8 students. Students' epistemological beliefs – essentially their knowledge of the formal epistemology of science – were measured using a survey instrument developed from the items used by Conley et al. (2004) whilst their personal epistemic beliefs were measured using a version of the instrument developed by Kuhn et al. (1999). The items from Conley et al. use a 5 point Likert scale, which has been previously validated, whilst those of Kuhn et al. pose a set of alternative judgements about knowledge claims and students have to judge which they consider to be 'true'. The nature of their response to these items and its consistency enables a judgement to be made as to whether they are epistemological absolutists, multiplists or evaluativists. The data from these instruments were analyzed using SPSS.

Students' understanding of the relationship between theories and evidence and the relative epistemic status of facts, theories and hypotheses was also measured by conducting 20 minute interviews with 6 pairs of students in each grade, providing a sample of 48 pairs in each year, and using an adapted form of the instruments developed by Driver et al. (1996). These interviews provide data both about students' practical epistemology that they deploy when confronted with the need to resolve conflicting evidence and their views about the nature of knowledge in science i.e. their formal epistemology. The rationale for using group interviews was that the opportunity for students to engage in discursive interaction with each other would produce more insights into student thinking and that this would be less intimidating – particularly for younger students. This does mean, however, that the unit of analysis becomes the group and not the individual. Thus in coming to a view about the meaning of the discourse, it was always the outcome of any student discussion that was coded rather than individual difference. Data from the interviews were analyzed using a coding schema which was in part grounded in the data (Strauss & Corbin, 1994) and in part driven by contemporary theoretical frameworks of what constitutes a sophisticated scientific epistemology (Hodson, 2008; Longino, 1990; Pickering, 1995). For instance, a particular interest was in how they saw the interrelationship between facts and theories. Using the schema, the interviews were coded and cross-checks conducted for reliability between three researchers. A reliability check between two researchers of one third of the sample attained agreement at the 83% level. Interviews were then coded using NVivo 8 to identify the major features in student understanding.

Results

Data from the Kuhn Instrument was categorised using their responses into a set of categories, which were:

Absolutist:	3 Absolutist Responses
Absolutist/Multiplist:	A mix of absolutist and multiplist responses
Multiplist	3 Multiplist responses
Evaluativist-	2 Evaluativist responses and another response, which was either absolutist or multiplist
Evaluativist	3 Evaluativist responses
Indeterminate	One response of each type

The distribution of responses and their percentages by year group are shown in Fig 1 and Fig 2 and Table 1

Grade 6

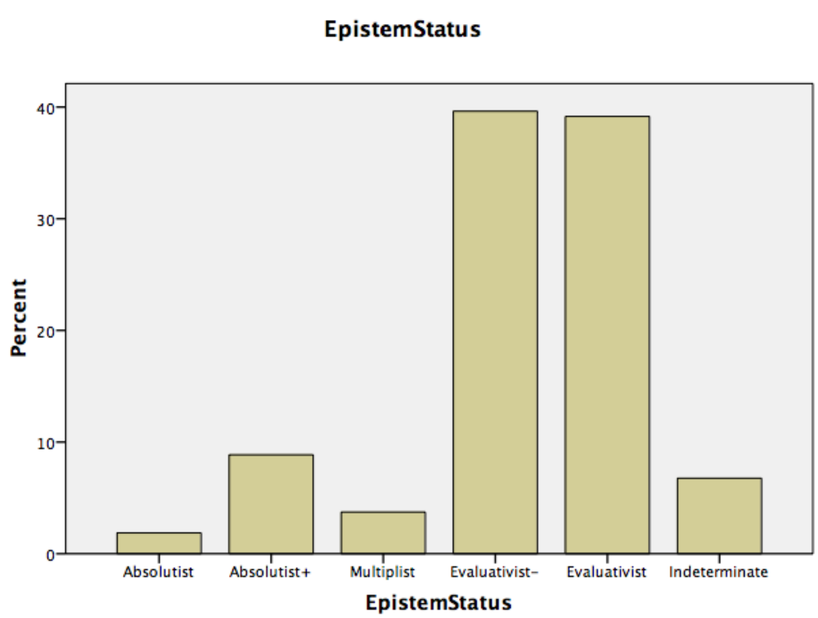


Fig 1: Chart showing Distribution of Personal Epistemologies from the Kuhn Instrument and the Grade 6 sample (n=429)

Grade 8

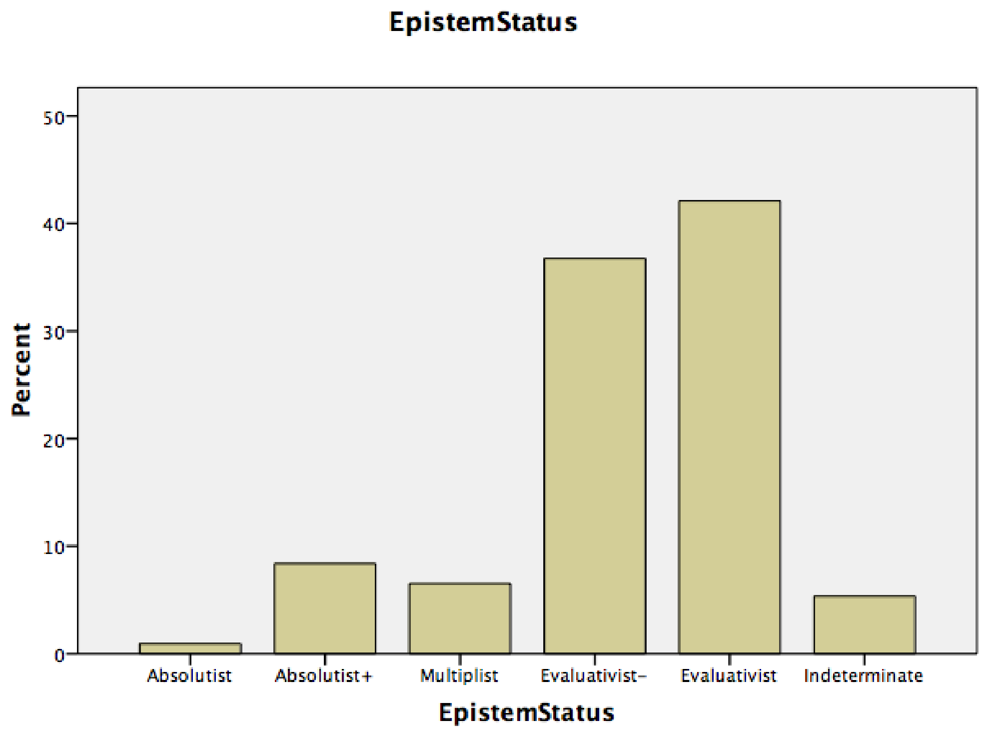


Fig 2: Chart showing Distribution of Personal Epistemologies from the Kuhn Instrument and the Grade 8 sample (n=430)

Epistemological Level		Grade 6 %	Grade 8 %
Absolutist		1.9	0.9
Absolutist+	2 Abs & 1 Multiplist 1 Abs & 2 Multiplist	8.9	8.4
Multiplist		3.7	6.5
Evaluativist-	2 Evaluativist + 1 Absolutist/Multiplist	39.6	36.7
Evaluativist		39.2	42.1
Indeterminate		6.8	5.3

Table 1: Table showing the percentage of students and their epistemological levels.

These responses show that the practical epistemology of most students can be assessed as evaluativists or near to that. Granted the assessment is made on a very limited number of items, would suggest that the data are an indication of how students reason rather than a consistent reliable measure. These data are triangulated, therefore, against other data, which we discuss beneath.

Measures of Epistemological Beliefs about Science

Students were asked to respond to a set of statements assessing their formal epistemological beliefs, which has 4 subscales. Factor analysis has shown these to be unitary and values for Cronbach alpha exceed .7 for all scales. Scales were scored on a 5-point scale from 'strongly agree' (1) to 'strongly disagree' (5). In the case of the Source and Certainty scales, disagreement was indicative of more sophisticated knowledge about epistemic beliefs in science. The reverse was true for the Development and Justification scales so these scores were reversed.

	Grade 6		**Grade 8**		**Conley Mean**
	Mean	SD	Mean	SD	
Source	3.34	.80	3.62	.72	3.68
Certainty	3.45	.77	3.69	.65	3.38
Development	4.15	.44	4.16	.44	3.90
Justification	4.22	.41	4.10	.46	4.26

Table 2: Mean values for Conley Scales and Standard Deviations

Conley's results obtained with US 5th graders using this instrument were higher than the values obtained here for Source and Justification but less for Certainty and Development. This is somewhat surprising given that our data were obtained from students in Grades 6 and 8 who were at least one, if not two years older. There was a significant difference ($p<.01$) between Grade 6 and Grade 8 students in the sophistication of their views about Source, Certainty and Justification of scientific knowledge. No such difference existed for the Development scale. However, in all cases the differences are not large. The important feature is that the mean responses for Source and Certainty have improved between Grade 6 and Grade 8. The same is not true for Development, which remained almost the same across the two age groups. What is also of interest is that both our younger group of Grade 6 students and Conley's 5th graders do better on the Justification scale than the Grade 8 students.

An analysis of the correlation between student responses to the Kuhn items (a measure of their practical epistemologies) and their mean response for the Conley items using Spearman's Rank Correlation coefficient gives the following data:

	Grade 6	**Grade 8**
Source	.163**	.252**
Certainty	.300**	.248**
Development	.063	.138**
Justification	-.034	.011

Table 3: Correlations between students' practical epistemologies and their formal epistemologies ($p<0.01$)**

The main feature to emerge from this analysis is that, whilst significant for both the Source and Certainty scales for Grade 6 and Grade 8, and significant for the Development scale for the Grade 8 group, the correlations in all cases are only small. In the case of the Justification scale the relation is not significant and there is an indication that the two are negatively associated for Grade 6. The lack of a stronger correlation is, at first site, somewhat surprising. One possible explanation is that this finding is a consequence of the fact that most students are relatively sophisticated in both their personal (practical) epistemologies and the ideas that they held about the formal epistemology of science, which would weaken the strength of the association between the two measures. Another, which we will discuss later, is that these instruments activate different epistemological resources, which are relatively unrelated.

Analysis of Student Interviews

Student Interviews were conducted with a total of 108 pairs of students, 54 from grade 6 and 54 from grade 8. The interview schedule explored both their knowledge of the formal epistemology of science – in particular, their understanding of the role of facts, theories and evidence in science and their practical epistemology by asking them to consider two instances where there were multiple competing explanatory theories. In the first of these tasks (Task 1) they were asked to decide between two contrary theories for how we see (because light enters the eyes or because vision is active) and, in the second (Task 2), between three differing explanatory theories for why things float and sink – none of which were scientifically correct. The particular focus of this work was on whether they were able to identify whether evidence supported one theory, challenged another or was irrelevant. In particular, whether they recognized the existence of a conflict, and how they then resolved the conflict generated by evidence, which challenged the existing theory that they had initially supported. Interviews were coded with a schema, which was developed over several iterations to capture the main themes in the interview. The final coding schema contained 42 codes grouped under 11 major categories, which were:

Nature of Climate Change
Conceptions of Facts
Conceptions of Theories
Comparison and Connection of Theories and Facts
Coordination of Theory and Evidence
    Theory Choice
    Justification of Theory Choice
    Dealing with Conflicting Data
Sources of Knowledge in Science
Tentative Nature of Science
Conceptions of Scientists Work

Understanding of Scientific Epistemology

The interview began with asking students whether they felt ideas about climate change to be a fact or to be a theory. 28% of the pairs felt it was a fact and 51% to be a theory while 21% thought that it might be both. Predominantly, those who believed it to be a fact referred to the levels of CO_2 in the atmosphere as the evidence that gave it the status of a fact:

> Student: Because the way the climate is evidence that it is. Because of CO_2 and they have been measuring the air pollution.

84% of the pairs were able to give examples of facts, 81% examples of theories and 70% examples of both. The strongest feature to emerge from the interview was that in 96% of the pairs, the idea was advanced that facts were the product of theories that had been proved. This was very much articulated in terms of notions that things could be seen and had been tested:

S1:	You can prove it.
S2:	Yeah, it is that you it's been proven that it's changing, you can't say that a football is not a football, you can't...it is a fact, isn't it? It's like...
S1:	It has been proven, like all the tests have been carried out millions and billions of times.
I:	Why do you say millions and billions?
S1:	Well, not millions and billions, but you have to make sure that facts either accurate...
S2:	...or reliable.
S1:	Or reliable.

Theories in contrast were felt to be tentative ideas, opinions or guesses (89%) – something that people believed and were, therefore, open to question:

I:	So what do you mean when you say the word theory. What does that mean for you?
S1:	It's an idea.
S2:	A thought someone has had. They don't know if it's true. They are just guessing.

S:	But an opinion is like a theory. Scientists start with an opinion or a theory
	------------------
S1:	A theory is what people think.
S2:	Yes it's not solid as a fact. It's more what people believe.

Our data show that students overwhelmingly see the status of a fact as representing the ultimate achievement of scientific knowledge. In some senses, there is nothing particular new about this finding which has been established by previous work (Driver, Leach, Millar, & Scott, 1996; Lederman, 1992). Nor would we wish to argue that students' who make this point are epistemological absolutists. The other data that we have gathered would not support such an interpretation. Rather, it would seem to us that students are most likely using the notion of 'proof' in the sense that the knowledge is beyond question – very much in the scientific sense that this is a piece of reliable knowledge that has been consensually agreed by the scientific community. Facts then are statements about the world, which have been shown to be true, verifiable and beyond question. As Latour and Woolgar (1986) have pointed out, such knowledge is very much the foundation of textbooks and very much the bread-and-butter of what most science curricula address. In this context, it is positive that at least 36% of the cohort did acknowledge that theories were more important than facts, while 33% recognized that they were of equal importance, and 41% saw that they had predictive value.

However, the issue of concern for us is that 89% of students predominantly hold the lay conception of a theory as little more than an educated guess, especially when only 13% recognized that they had *explanatory* value. Fig 3 beneath shows that this perception varies little between the two grades even though the students' level of conceptual knowledge, as measured by a national examination in grade 5 and grade 8 varies considerably (Fig 4). This would suggest that their education in science to date has failed to provide them with a sense that the apotheosis of science is the creation of theories that offer a coherent explanatory framework for a miscellany of observations – such is the achievement of the Copernican heliocentric theory, Darwin's theory of evolution or Wegner's theory of plate tectonics.

Fig 3: Data for students' ideas about the role of theories in science for Grade 6 and Grade 8

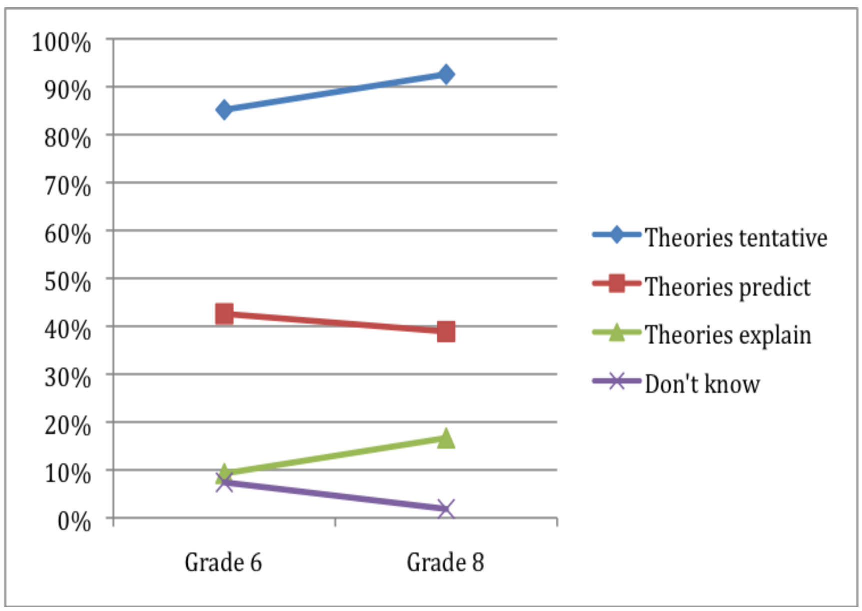
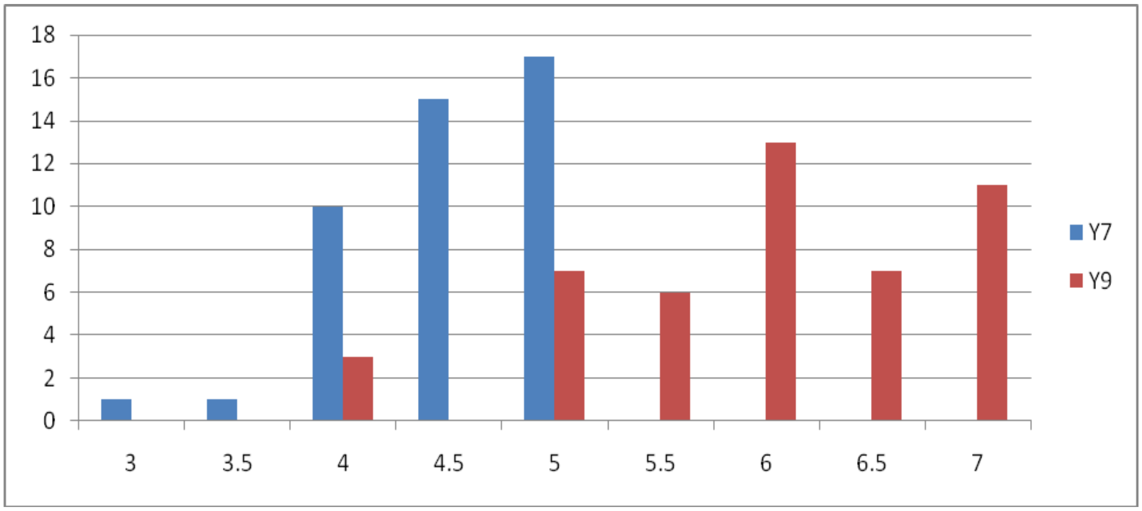


Fig 4: Student performance on National examinations at Grade 6 (Yr 7) and Grade 8 (Year 9)



The lack of any association between these performances would suggest that content knowledge and its development is separate from the development of any meta-knowledge about the nature of science itself.

Evaluating Theories

The two tasks we offered the students examined their ability to coordinate theory and evidence. Task 1 gave students two theories to discuss about how we see and has been extensively used in previous research. The first finding of note in this work was that 99% of student pairs picked the scientific theory as the one that they thought was correct. This finding challenges the work of Guesne (1978) and Andersson and Karrqvist (1983) which suggested that the proportion of children who believed vision to be the outcome of an active, not passive, process was large and that the physicists' model was rare. What was of note in this study was that in both task 1 and task 2, nearly all students were capable of explaining how some of the evidence that they were presented with did or did not support their chosen theory. For instance, in the discussion of whether 'light travelling in straight lines' for Task 1:

Int:	So light travels in straight lines. How does that relate to the theory? Does it agree or disagree?
S2:	Disagree. 'Cause it is not saying that...
S1:	It's not saying that they don't travel in straight lines but it is not saying that they do. And I already know that's true.
S2:	Yeah.
Int:	So do you think it agrees or disagrees or does it not matter?
S1:	It doesn't agree but it doesn't disagree.
S2:	I think it agrees with both of what they say but I don't think it really has that much relation with what they think, because they are talking about how they travel.

And in discussing task 2:

> Int: So what do you think would happen to a toy car?
>
> S2: Based on that theory I think it would float.
>
> S1: Yeah.
>
> Int: Why do you think it would float based on that theory?
>
> S2: Because it's more light, it's not as heavy as a real car

Indeed, 94% went beyond using the evidence provided in the task using supplementary evidence, not supplied within the interview, to justify their choice.

> S: Because with theory one, some things that are heavy can float. Like avocado, I watched someone drop an avocado and dropped it and like floated and it's quite a heavy object but it floats.

Students explored the role of evidence and its relationship to theory extensively in both of these tasks. Coding shows that their discourse was dominated by attempts to explain how the evidence did or did not support the theory – a finding which is unremarkable given that this was the task that they were asked to address. However, approximately a quarter to one third were attempts to justify their theory choice using their own evidence. Table 4 beneath shows the percentage of coding references obtained in each category by age group:

	Grade 6	*Grade 8*
Explain Evidence	39.8%	45.3%
Use Own Evidence to Explain	31.1%	25.2%
Unprompted Coordination of Theory and Evidence	4.8%	2.8%
Inappropriate Use of Evidence	12.4%	13.1%
Justifications other than Evidence	5.3%	6.3%
Familiarity with Phenomenon	6.5%	7.2%

Table 4: Percentage of coding references used by students in responding to question asking them to coordinate theory and evidence in Grade 6 and Grade 8.

Our interpretation of these findings is that they suggest that students, when pressed, see that claims to knowledge require justification and, in that sense, can be said to be behaving as evaluativists. Not all of these justifications were evidence-based and some tended to be advanced in terms of justifications other than evidence.

> S2: Because it is just like telling you that things that are light float and things, it is just basically saying that's why. And that is it really. It is not saying why it happens. And the second one is the same because they contain air. So it is giving you more of an idea about why.

Such explanations are justified epistemically in that the explanatory power of a theory is a common scientific criterion used by scientists to judge its value. Scientists commonly use intrinsic values which are variously described as: mechanistic, materialistic, masculine, reductionist, idealized, objective, impersonal, rational, universal, communal, value-free, disinterested, parsimonious, authoritarian, socially sterile, positivistic (Putnam, 2004) to assist in making judgements about claims to knowledge. Students here are simply attempting to do something similar. Explicit reflection on such reasoning might help them to become more aware of some of the manner in which judgements can be arrived at in science.

Another common form of reasoning was that which drew on a familiarity with the phenomenon. Commonly the claim to knowledge was made because it was either something that they had been taught or that they had read.

Int:	What do you think? Why did you immediately say theory two is right?
S1:	Because that is what I know.
Int:	How do you know that?
S2:	We have done it in science.
S1:	That is what we've been taught.

S2:	We just know it, it's a fact like you have read it in books and stuff. You just know it.

Again, such claims should be seen as normative warrant which of the type commonly used by many adults and teachers. Such reasoning is simply one of the epistemic resources deployed in argumentation and should not be seen as indication of a dogmatic belief in authority or reflecting an absolutist epistemology.

There was less explicit indication in the interviews that students saw science itself as being a process, which required an evaluative approach. 19% of students mentioned spontaneously that science was tentative making statements such as:

S2:	Because in science there is not just one answer, there is a lot of answers.
Int:	To the same thing?
S2:	Yes.

S1:	Sometimes facts can be proven wrong though.
Int:	Why do you think that?
S2:	Like when you say the earth is round. People used to think the earth was flat until they got proven wrong.
Int:	So you can have some facts and we think that they are true and then…
S2:	Yes, because if you have like the right equipment to like prove it wasn't right.
Int:	So we change the facts?

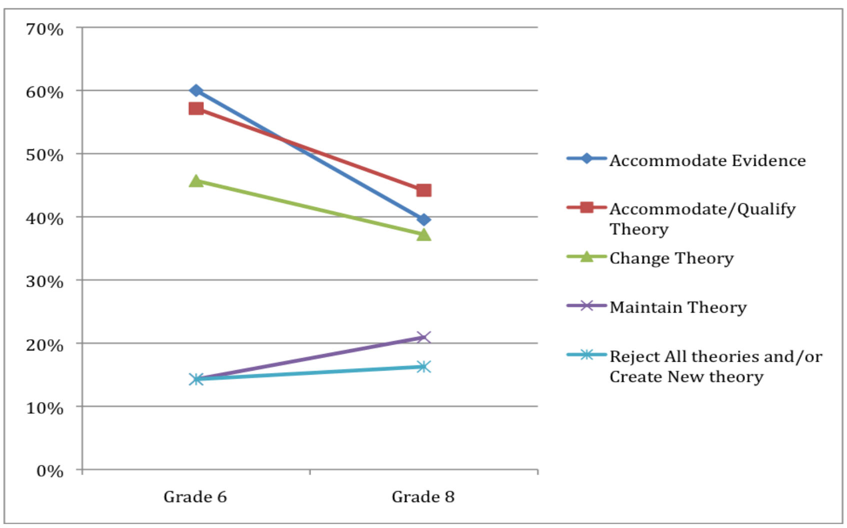
R2: Yes.

The conclusion we draw from our analysis is that students' practical epistemologies, when confronted with the need to co-ordinate theory and evidence show some degree of sophistication. 72% of students recognised the conflict and Table 5 beneath shows the standard ways in which they were found to respond.

Mode of Response	Percentage using this response
Accommodates Evidence	33.3%
Changes Theory	34.6%
Qualifies/Accommodates Theory	35.9%
Maintains Theory	14.1%
Reject all-Creates new Theory	15.4%

Table 5: Mode of Response to Conflict (total more than a 100% as some students used more than one way of resolving the conflict)

Fig 5 shows how this varied between the two grades



One third of students did change their theory in the light of conflicting evidence. Again, the failure to change theory or to develop a new theory in the light of cognitive conflict should not be seen as an epistemological weakness. The work of Chinn and Brewer (1993) and Leitão (2000) has shown that it is rare for this to be the immediate response to conceptual conflict. What is perhaps more notable is that there was only a small number of students who realized that none of the theories was adequate and that this number did not vary substantially between the two grades.

Conclusions, Implications and Contribution to the Field

Any conclusions to be drawn from this data set are tentative given its limited nature. We recognize that there are considerable weaknesses in attempting to identify either students' epistemological beliefs or their practical epistemologies from a short survey instrument and even the short qualitative interviews we have attempted to conduct (Lederman, Abd-el-

Khalick, Bell, & Schwartz, 2002). Nevertheless, what this study does offer uniquely is three data sets that give different windows into students' reasoning and their epistemic beliefs about science. Of interest to us are two questions: first what does this data set say about students' practical epistemologies, their understanding of scientific epistemology and their similarities and disparities; second, how do these findings compare with the work of others and add to our overall picture of work in this field.

The data we have obtained from the instruments of Kuhn and from the interviews would suggest that students' practical epistemologies could be characterised as evaluativist or at least inclining towards such practices. Such an outcome is congruent with the findings of Smith et al. (2000) which found that students taught using a constructivist perspective developed an epistemological stance toward science that focused on 'the central role of ideas in the knowledge acquisition process and on the kinds of mental, social, and experimental work involved in understanding, developing, testing, and revising these ideas'. Whilst our data consists of only two sets it is at least indicative of some underlying coherence to their practical epistemologies. In one sense this data does not support Hammer and Elby's (2002) view that personal epistemologies as a loose collection of resources which are invoked by different contexts – in essence a collection of epistemological primitives which are comparatively unrelated. However, the items posed to these students were specifically asking them to take a stance towards certain specific knowledge claims. These would be most likely to trigger Hammer & Elby's epistemological primitive of 'doubting' or 'accepting' and hence, the coherence in these two contexts which do not call upon the other primitives. Evidence that the students do use such evaluative reasoning also comes from the interviews where over two thirds of the students at both grade levels either attempted to provide an evaluative judgement of how the evidence did or did not support a theory, or alternatively, used their own evidence to justify their theory choice.

When it comes to students' understanding of the formal epistemology of science, the interview would suggest that they hold less developed views of scientific epistemology where the primary goal of science is seen as the creation of certain and unequivocal factual knowledge. Few seem to recognize that it is the theoretical accounts of the material world and their explanatory power, which is the ultimate goal and that facts are simply the handmaiden to this goal rather than the end in itself. This picture is, however, contradicted by the data from the Conley instrument, which would suggest that students lean, on average, towards a more sophisticated view.

One possible explanation is that students' responses to the survey could be said to be drawing on Hammer and Elby's notion of 'knowledge as fabricated stuff' where knowledge is seen as something that is constructed and hence tentative and associated with an element of uncertainty which would explain why they appear to be relatively sophisticated. In contrast, the questions in the interview, coupled with their experience of school science, activate the epistemological primitive of 'knowledge as propagated stuff' – an understanding that sees knowledge as preformed and only valid if it has been shown to be 'true' and has acquired the status of a law or a 'fact' (Lederman, Abd-el-Khalick, Bell, & Schwartz, 2002; McComas, 1996). Hence the tendency to ascribe a higher epistemic status to 'facts'.

This leads us to the view that the way in which knowledge is framed within school science draws too much on the notion of 'knowledge as propagated stuff'. Rather, there needs to be more focus on the notion of 'knowledge as fabricated stuff'. This does not simply mean engaging in more experimentation. In our findings, 49% of students' commented spontaneously on sources of knowledge in science and their responses were dominated by the notion that experiments are critical tests of scientific ideas – essentially the epistemic criterion that must be satisfied to establish something as a 'fact'. Rather, we would wish to suggest, along with Ford, that activating the epistemological resource of 'knowledge as fabricated stuff' requires students to have the opportunity to engage in critical evaluation of ideas and data. It is only this practice that will enable students to see that science is not simply a monolithic body of pre-formed knowledge but that rather scientific ideas are developed by a process of transformative criticism. Indeed that the fabrication of new ways of conceiving of the world is a more fundamental, and more important aspect of science than propagation.

Such an approach would also have value for student learning as a clear relationship between epistemic beliefs and conceptual change has been shown to exist (Andre & Windschitl, 2003; Qian & Alverman, 2000). Students who view knowledge as flexible, changing and fabricated are ultimately more likely to change their conceptions about scientific phenomena. Moreover, students who see knowledge as something which has to be socially and personally constructed are more likely to accept scientific explanations of phenomenon (Sinatra, Southerland, McConaughy, & Demastes, 2003). Hopefully, this paper has contributed better to understanding the interrelationship that might exist between students' formal understanding of scientific epistemology and their own practical epistemologies. What it demonstrates is that there is some inter-relationship between the two and, just as it is impossible to imagine constructing a house without a roof, likewise, it is impossible to imagine helping students to understand the importance of theories, evidence and their inter-relationship unless students are provided with more opportunity to see how ideas in science are both constructed *and evaluated.*

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