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PAST AND PRESENT CHALLENGES TO ENQUIRY LEARNING IN TERTIARY SCIENCE EDUCATION

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Abstract

Early last century, educators bemoaned the quality of science learning, stating that it should be a process of enquiry where students learn a way of thinking, and knowing, rather than a process of rote memorisation of science content and facts to be regurgitated in exams. Dewey, Schwab and Bruner stated that for meaningful learning to occur students must engage in experiences reflecting the way science is done. In the 21st century, this narrative has re-emerged in curriculum documents worldwide and there is now a broader acceptance that science learning should be in some way reflective of the "doing" and "discovery" in science as well as meet the needs of citizens living in a supercomplex world. To create such an enquiry curriculum at the tertiary level we need academics who can develop learning and teaching experiences which provide enquiry research experiences for students that demonstrate the contestable and rigorously uncertain nature of scientific knowledge. This study asked academics for their perceptions of the success of implementing an enquiry pedagogy and developing an intentional curriculum. We found that although academics perceive certain curriculum drivers, such as enquiry, to be important, they perceived their own effectiveness in delivering these qualities in their teaching to be poor. It may be that academics cannot change the curriculum because they are restrained by structures, but the literature on science identity highlights that academics also reproduce structures. If we are to create a more enquiry and investigatory experience for students learning science then we need to surface any "defensive cynicism" and hidden disciplinary processes. Learning how to do the learning in the discipline will move our students forward into science research careers and produce graduates and citizens who are scientifically literate.

Keywords

enquiry learning, science, science education, curriculum

Introduction

What is enquiry learning?

Enquiry learning has been defined as instruction which reflects the investigative approach, empirical techniques and reliance on evidence that scientists use in making discoveries and constructing new knowledge (Cobern et al., 2010). Current thinking suggests that there is no 'one' method of scientific enquiry and that the ways of doing science are as diverse as scientists and the ways they study the natural world (Elliot, Sweeney, & Irving, 2009; Elliot, Boin, Irving, Johnson, & Galea, 2009, 2010; National Research Council, 1996). In a tertiary context, scientific enquiry has the dual purpose of training new researchers (Johnson, Elliott, Boin, Irving, & Galea, 2009) and science graduates who have a knowledge and understanding of scientific ideas and how scientists study the natural world (National Research Council, 1996). It is also a pedagogy used to create a scientifically literate citizenry, whereby students draw evidence-based conclusions about science-related issues, increase their understanding of the characteristics of science as a form of human knowledge, are aware of how science and technology shape our material, intellectual and cultural environments, and engage in science-related issues and ideas as reflective citizens (OECD, 2006). Yet at the tertiary level, although enquiry based learning is perceived as important, in practice experiences for students are fragmented throughout their degree and there is little empirical evidence available to evaluate whether graduating students are indeed scientifically literate (Elliot et al., 2010).

Enquiry learning: A historical perspective

Enquiry learning in science has a history. Last century, it was John Dewey who first commented on the teaching of science, stating that science should be taught as a way of thinking and a process of knowing; to be valuable within the lives of students and worthwhile for the intrinsic contribution to the experience of life (Dewey, 1910, cited in Rice, Thomas, & O'Toole, 2009). Yet, it was perhaps two millennia ago that the dichotomy for the learning of products or facts versus process in the learning of science began, when Plato planted the seeds for a two-tiered system of education; the auxiliaries and the policy makers. The auxiliary classes were taught doctrine, truths beyond questioning, while the policy makers were conditioned to uncertainty, the best available opinion, open to systematic doubt, incomplete and explicitly encouraging of continuing enquiry (Schwab, 1962). Schwab (1962) wrote about this two-tiered way of thinking to plead for the universal training of a reflective intellect and sceptical intelligence and the need to convey a view of learning science as enquiry, reflecting the true character of the discipline. Schwab (1962) called for a science learning curriculum with pedagogy of "enquiry" to be juxtaposed against science teaching as "dogma" with rhetoric of conclusions; imposing the false impression of science learning as literal, irrevocable, inalterable truth. He stated that an enquiry approach would ensure that scientific conceptions would be open to question and students open to uncertainty and complexity; needed for autonomous thought and thereby "relinquish the habits of passivity in favour of active learning" (Schwab, 1962, p. 66). It is this notion of the intrinsic motivation or "increasing intellectual potency" (Bruner, 1961, p. 23) gained by students through enquiry learning, which was added to the debate. Bruner (1961) emphasised that instruction must be concerned with the experiences and contexts which make students willing to learn; rather than experiences which encourage mastery of facts and techniques. He stated that our aim as teachers "was to make students autonomous and self-propelled thinkers" (Bruner, 1961, p. 23) and that an enquiry approach would create surprise which "favours the well prepared mind" (Bruner, 1961, p. 22). Philosophically, it was through such an enquiry approach that the "science doing" and the "science learning" or thinking and knowing in science learning might be brought into synergy.

Almost immediately, Schwab's and Bruner's approaches to the learning of science were criticised on numerous grounds: (i) for naivety, for confusing the learning with practising of the discipline, for confusing means with ends and for inefficiency (Wittrock, 1966); (ii) for fraudulency in suggesting that real science discoveries could be made by students (Ross, 1994); and, (iii) that these approaches were based on a simplistic positivist notion of the scientific methodology which does not exist (Kuhn, 1962).

With the rise of constructivism, came new criticism. Novak (1988) argued that the obsolete epistemology of enquiry was not only responsible for the shortfall in expectations of the major effort to improve science education in the 1950s and 1960s, but that enquiry-orientated science was the major barrier in the way of revolutionary improvement of science education. Others agreed, and enquiry activities undertaken in laboratory work came under increasing scrutiny for their ineffectual influence for dealing with students misconceptions which left unchallenged scientifically unacceptable conceptual understandings (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Novak 1988; Solomon 1988). Novak (1988) made clear the distinction between "learning science and the science of learning" lamenting the lack of evidence of learning gained in laboratories where enquiry learning occurred. He stated that students gained little insight into either key science concepts or process in laboratories because of an instructional misconception that physical activity and cognitive gain were somehow equivalent (Hodson, 1990, 1993).

More recently, enquiry learning has been once again under attack for its naive intuitive appeal, but lack of learning gains as measured by student performance (Mayer, 2004). The most recent well-published criticisms are similar to those of Novak (1988) and Solomon (1988). Although enquiry learning may be popular with students and academics alike, enquiry learning is considered a naive pedagogy because it ignores cognitive load and architecture (Kirschner, Sweller, & Clark, 2006; Tuovinen & Sweller, 1999). Dichotomies such as those created by Kirshner et al's, (2006) polemic and the continued debate about superiority and purity of a minimally guided and unscaffolded environment compared to direct, explicit highly scaffolded instructional teaching (Cobern et al., 2010; Hmelo-Silver, Duncan & Chinn, 2007; Kirschner et al., 2006; Mayer, 2004) may help to focus arguments, but ultimately are unhelpful in providing guidance. Perhaps part of this debate arises because of the context of learning in the tertiary learning of science is physically and argumentatively separated. The 'learning' or the 'doing' of science is mainly restricted to the practical laboratory or fieldwork (Hodson, 1993); while the 'science of learning,' that is, the chunking of information (Novak, 1988) occurs in lectures. Indeed, after moving through a period in the 1980s and 1990s where learning in the laboratory was derided (Novak, 1988; Solomon, 1988), it is now recognised that the learning that does occur in the laboratory has not had appropriate acknowledgement (Hart et al., 2000).

What is clear from the debates throughout the ages is the continued need for science learning at tertiary level to reflect the investigative approaches, empirical techniques and reliance on evidence that scientists use in making discoveries and constructing new knowledge (Cobern et al., 2010). It is essential *sine qua non* for undergraduate students to experience how universities produce new knowledge through specialized processes of enquiry., These processes, that underpin the research enterprise of universities, could be harnessed to learning and teaching renewal through teaching approaches that enable professional researchers and students to co-construct knowledge and negotiate meaning (Healey & Jenkins, 2009). It is also in this way that science learning and teaching strategies at Universities can lead to meaningful, relevant learning and motivated learners (Ausubel, 1960). The massification of university education, the consequential large first year class sizes and declining resources mean that enquiry-based learning becomes difficult to implement (Rodrigues, Tytler, Darby, Hubber, Symington, & Edwards, 2007). Yet, enquiry-based learning is appearing as an overarching theme in many national and international curricula, for example, the National Australian Curriculum, Australia and reports (Rice et al., 2009; Singer, Hilton, & Sweingruber, 2006). Coupled with this is a call for a reconceptualisation of undergraduate tertiary science teaching to a more active, realistic and enquiry basis within the curriculum (Rice et al., 2009; Ross & Tronson, 2007; Weiman 2007).

Unfortunately, the evidence is that even with enquiry pedagogy and curricula in place, there is a considerable gap between the intended ideas embedded in the curriculum documents and the actual curriculum experienced by the students (Goodrum, 2006). Within tertiary institutions, although the call for enquiry learning laboratory experiences has started to gather momentum and the need to provide students with a range of research experiences is generally accepted, adoption, especially in the early years, has been slow.

Further, although there is widespread belief that research experiences for students are essential, there is little evidence that the teaching of scientific enquiry skills at tertiary level leads to positive learning gains (Elliot et al., 2010; Rice et al., 2009). There is also little empirical evidence on what science academics, mainly engaged in research, perceive to be the critical curriculum drivers in the learning of science at a tertiary level. If there is consensus among academics of the importance of an engaging, enquiry-investigatory curriculum within their discipline, then what are these same academics' perceptions of the success of implementing such a pedagogy and curriculum?

Case Study

This study was undertaken in a science and health-based faculty within a major metropolitan University. The aim was to investigate the importance of curriculum drivers, including enquiry, within different scientific disciplines, and the academic teaching staffs' perceptions of the success of implementing such a pedagogy and curriculum. Academic teaching staff came from various disciplines within biomedical and health science, natural science, computing and mathematics. There were 28 questions (Table 1) posed to 31 staff who rated their perception of both the importance of each key curriculum driver and their own effectiveness or performance in delivering each within their teaching practice. A Likert scale was used, where 5 was Strongly Agree and 1 was Strongly Disagree. The response rate was 100%.

Table 1
*Correlations between the responses of academics to the importance and performance of items reflecting the key curriculum drivers in a tertiary Science curriculum (** indicates P <0.01)*

Category	R^2	P	n
Learning and Teaching Approaches			
1. Maximise opportunities for active learning	0	-0.01	23
2. Ensure learning experiences are immediately relevant to the backgrounds, abilities and needs and experiences of students	0	-0.13	21
3. Make explicit the relevance of studies to professional disciplinary and personal contexts	0.1	0.17	21
4. Provide opportunities for community engaged learning experiences	0.1	0.27	20
Total	0	0.34	25
Curriculum design			
6. Intentional mapping and scaffolding of knowledge and learning objectives across core and key programs	0.3	0.0092**	22
7.Explicit linking of theory and practice	0	0.36	23
8. Ensures that learning proceeds in digestible chucks and has a clear and integrated directions	0	0.63	23
9. Identifies core capabilities and skills planned and developed across the whole curriculum.	0.1	0.34	22
Total	0.1	0.16	23
Conceptual and Contextual			
10. Content is set within the contexts that are meaningful and relevant to students	0	0.67	31
11. Greater selectivity in the coverage of the content	0	0.47	28
12. Selection of content which represents real science e with a view to the usefulness in students' current and future lives as scientists and citizens	0.1	0.09	29
13. Prioritises difficult concepts to underpin the discipline over rote memorisation of facts	0	0.41	30
14. Increases active engagement and learning by students	0	0.74	30
15. Increases the knowledge basis within the curriculum	0	0.55	29
16. Covers the big and engaging ideas in the first year of students experience	0	0.5	27

17. Leaves recent research and interesting ideas in science to second and third year rather than first year	0	0.48	25
Total	0	0.57	31
Investigative			
18. Inquiry or investigative design included which covers a wide range of methods and principles of evidence	0	0.45	29
19. Collaborative investigations which develop critical thinking, communication and report writing skills	0	0.4	29
Total	0	0.45	29
The Doing of Science, the scientific method and nature of Science			
20. Widens the curriculum to include an understanding of the nature of science	0	0.51	29
21. Increases experiences of evidence based inquiry	0.1	0.08	28
22. Decreases the amount of undergraduate research experiences (URE)	0	0.66	26
23. Increases the evaluation of scientific research on the basis of validity and sound experimental design	0	0.77	26
24. Increases the amount of content to emphasise facts and recall.	0.1	0.13	25
Total	0.1	0.07	29
Integration			
25. Across disciplines	0	0.89	29
26. Within disciplines which integrates theory and practice	0	0.59	28
Total	0	0.47	29
Creativity and Curiosity			
27. Embeds authentic real science experience	0	0.59	28
28. Increases creativity and imagination	0	0.82	26
Total	0	0.75	29

Results

Overall, academics rated the importance of almost all curriculum drivers greater than they rated their own perceived performance or effectiveness in delivering them (Figures 1-7). Almost all correlations between importance and an academic's perception of performance were non-significant, suggesting no substantive relationship between importance and how well an individual academic thinks they perform their teaching duties. There were also no significant correlations when appropriate corrections were made for multiple tests (Table 1). Most of the academics thought that their performance was not adequate on a range of curriculum drivers that they considered to be important (Figures 1-7). The lowest correlations were associated with questions 25-28; the areas of integration, creativity and curiosity with R^2 values ranging from 0.00-0.01 (Table 1 and Figures 6-7) indicating the poorest perceptions of effectiveness or performance by academic staff.

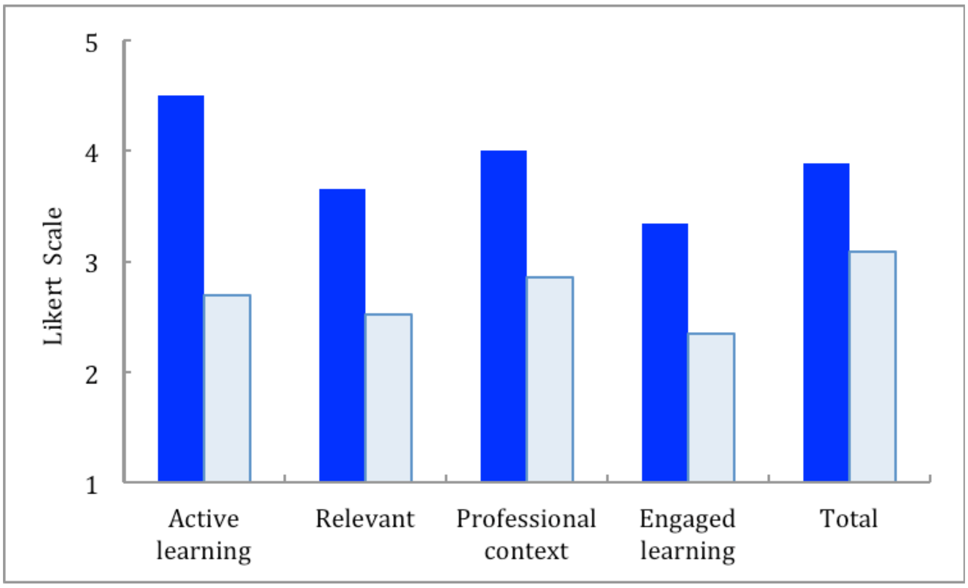

Figure 1. Responses from academics to a 1-5 Likert Scale for learning and teaching approaches which (1) maximise opportunities for active learning; (2) ensure learning experiences are immediately relevant to the backgrounds, abilities and needs and experiences of students; (3) make explicit the relevance of studies to professional disciplinary and personal contexts; (4) provide opportunities for community engaged learning experiences (5) mean value for learning and teaching approaches. Dark blue shading importance and light blue performance.

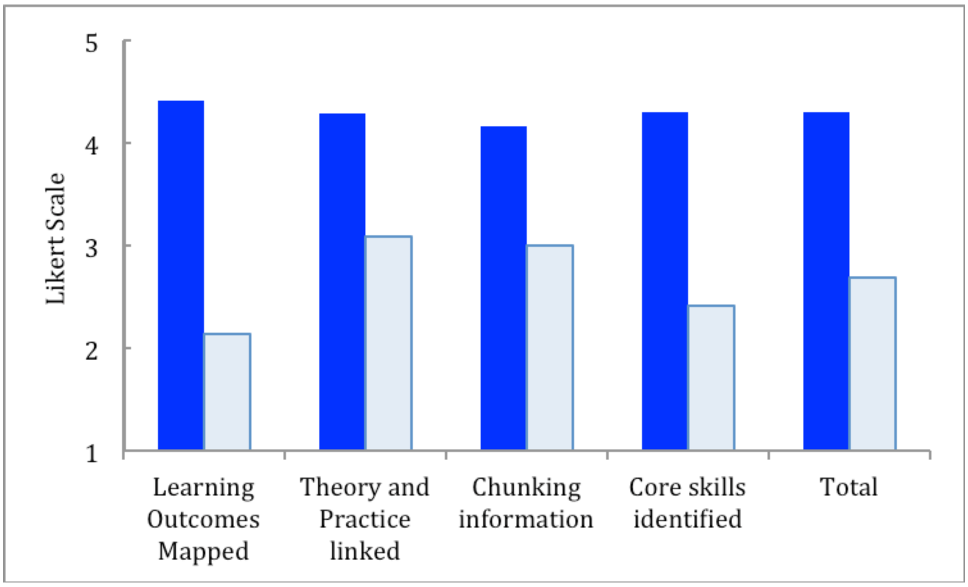

Figure 2. Responses from academics to a 1-5 Likert Scale for curriculum design which has (1) intentional mapping and scaffolding of knowledge and learning objectives across core and key programs; (2) explicit linking of theory and practice; (3) ensures that learning proceeds in digestible chucks and has a clear and integrated direction; (4) identifies core capabilities and skills planned and developed across the whole curriculum (5) mean value for curriculum design. Dark blue shading importance and light blue performance.

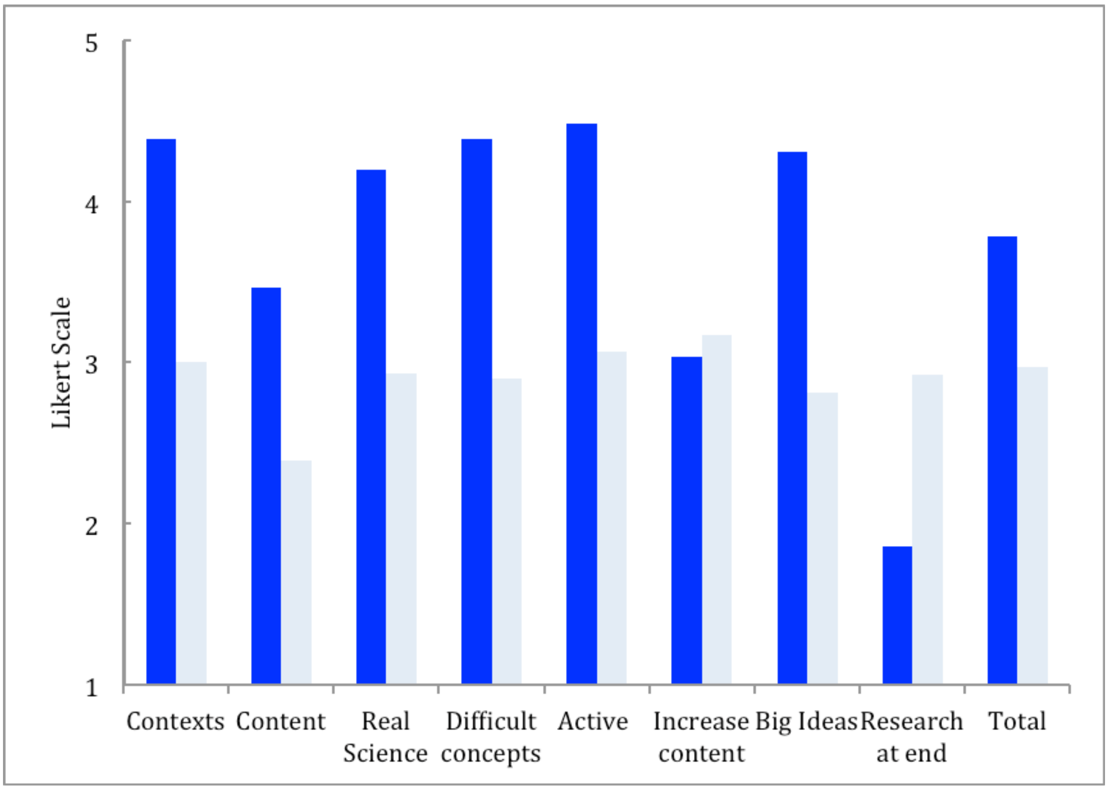

Figure 3. Responses from academics to a 1-5 Likert Scale for conceptual and contextual learning in which the content is set within (1) contexts that are meaningful and relevant to students; (2) greater selectivity in the coverage of the content; (3) selection of content which represents real science with a view to the usefulness in students' current and future lives as scientists and citizens; (4) prioritises difficult concepts to underpin the discipline over rote memorisation of facts; (5) increases active engagement and learning by students; (6) increases the knowledge basis within the curriculum, covers the big and engaging ideas in the first year of students experience; (7) leaves recent research and interesting ideas in science to second and third year rather than first year (8) mean value for conceptual and contextual approaches. Dark blue shading importance and light blue performance.

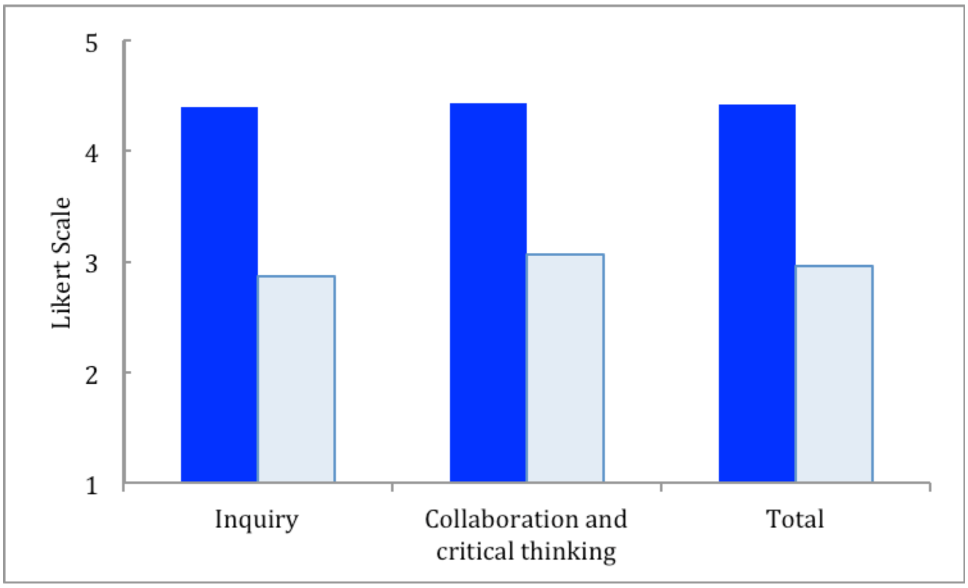

Figure 4. Responses from academics to a 1-5 Likert Scale for Investigative Science which includes a focus on (1) inquiry or investigative science which covers a wide range of methods and principles of evidence through (2) collaborative investigations which develop critical thinking, communication and report writing skills (3) mean value for investigative approaches. Dark blue shading importance and light blue performance.

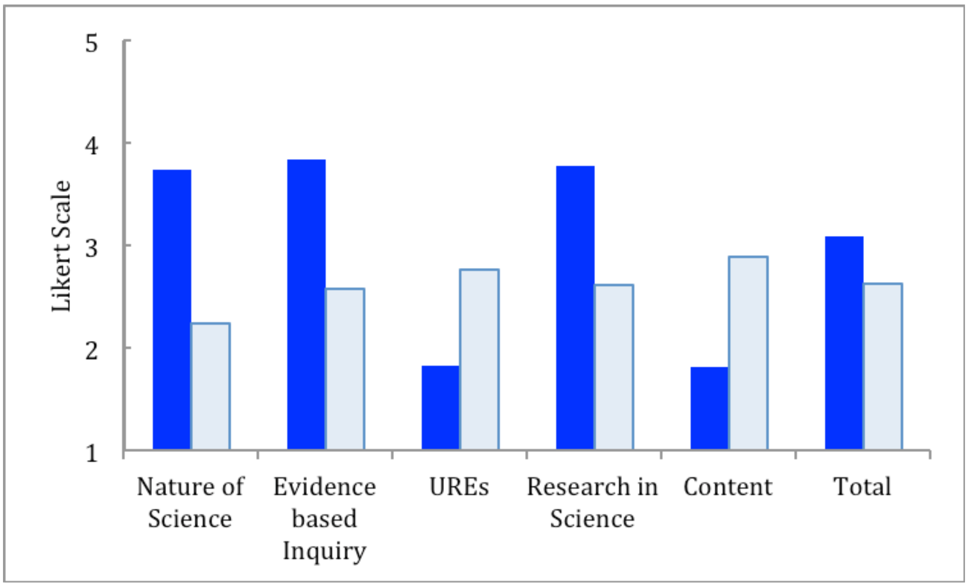

Figure 5. Responses from academics to a 1-5 Likert Scale for the doing of science, scientific method and the nature of science which (1) widens the curriculum to include an understanding of the nature of science, (2) increases experiences of evidence based inquiry,(3) decreases the amount of undergraduate research experiences (URE) in the curriculum (reverse or negative item); (4) increases the evaluation of scientific research on the basis of validity and sound experimental design and (5) increases the amount of content to emphasise facts and recall (reverse or negative item) (6) mean value for doing science, scientific method and the nature of science. Dark blue shading importance and light blue performance.

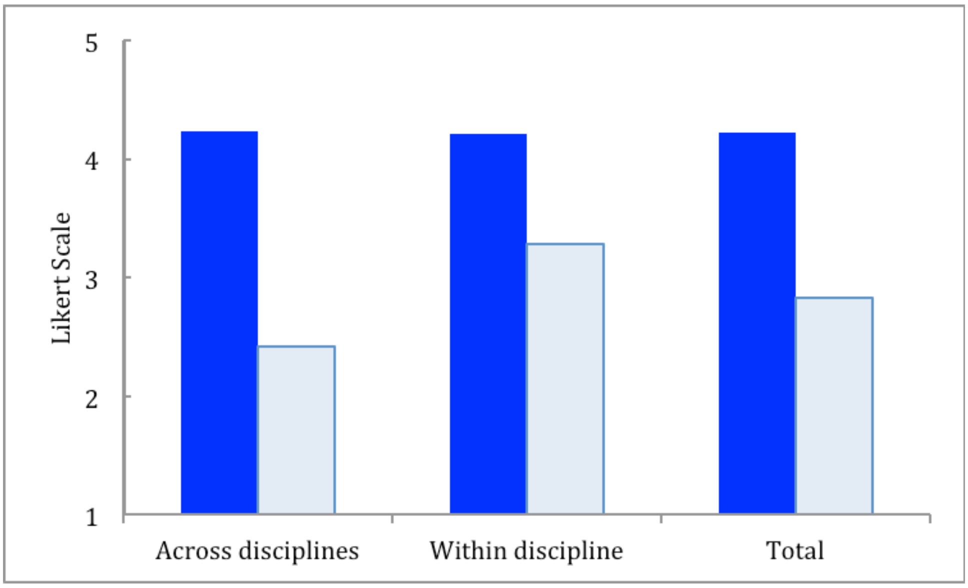

Figure 6. Responses from academics to a 1-5 Likert Scale for the importance of integration across (1) and within disciplines (2) so that theory and practice are linked (3) mean value for integration. Dark blue shading importance and light blue performance.

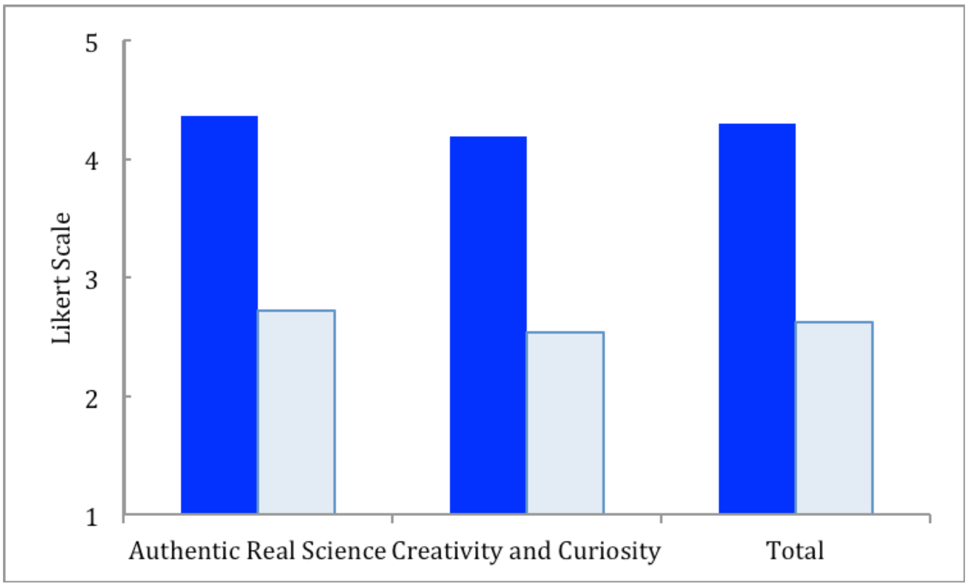

Figure 7. Responses from academics to a 1-5 Likert Scale for creativity and curiosity which embeds (1) authentic real science experience which (2) increases creativity and imagination. (3) mean value for creativity and curiosity. Dark blue shading importance and light blue performance.

Discussion

The results of this study indicate that academic staff over a wide range of scientific disciplines thought that teaching some topics by enquiry and of good curricula design fundamentals was important, but they felt that they were not performing well in the execution of these learning and teaching strategies. Such results indicate a gap between that which was perceived to be important in curriculum design and each and every academic's perception of his/her own performance. The items that rated highest in terms of importance were those which emphasised a curriculum of information recall (i.e. chunking) core skill development, prioritising of big ideas and contextual learning. These items have in common the knowledge and skills of science and the results reflect the continued importance of content and the transmission of information in learning science. The items that rated lowest in terms of importance were those of enquiry, the doing of science, scientific method and the nature of science including creativity and curiosity. If these results reflect the general perception and practices of science and mathematics academics at tertiary institutions, then many academics are not performing well (according to their own criteria or standards) in areas they perceive as important to student learning.

As predicted at the start of this study, the rhetoric of learning science at the tertiary level does not match the reality (Goodrum 2006). The intentions of an enquiry, investigatory "real science" approach to the learning of science at tertiary level differ to perceptions of how the actual curriculum is performed by academics and experienced by our students. National and international policy and curricula documents, however, reflected in the recent "Vision and Change" documentation from the National Science Foundation (Woodin et al., 2010) and the learning and teaching standards project (LTAS) of the Australian Learning and Teaching Council breathe new life into the goal of enquiry in learning science (Bybee 2003). There is once again explicit recommendation to engage students in the scientific process (Woodin et al., 2010). While undeniable that the learning of science requires the "science of learning" (Novak 1988) and "curricula coherence" (Bybee 2003) using models of learning of science (Novak 1988; Reid 2008; Ross et al., 2010), there must also be congruence between science as a way of knowing, a human endeavour (Bybee 2003). The thinking processes in science need to reflect a way of knowing which is integrated and can be demonstrable and assessable. If then we have such agreement on what indeed is importance. What then makes it difficult to change? Is it perhaps the structure which prevents a change in academic practice? T There is certainly a sense in many facilities of the dominant order, 'establishment' or ideology in science education that validates what counts as effective science learning. Yet in being so rigid and exclusive this 'dominant perspective' has failed to keep pace with the educational challenges created by an increasingly 'uncertain' world required for scientific literacy and citizenry. The literature on science identity (review Shanahan 2009) suggests that although such structures can shape academic practice, it is also the academics that constitute and reproduce structures (Sewell 1992) and perhaps most alarmingly subsequently constrain the availability of science identities to students.

Although structure may be a current restrain, there are also other barriers. The literature from the coal face suggests that academics do not perceive themselves as the problem; rather they suggest that the barriers to change exist within students (Weiman et al., 2010). The "deficit" view of the student (Haggis 2006 p. 522, Wingate 2007) locates the responsibility of progress in academic curricula on the "quality" of the student. Haggis (2006) states that there is a "defensive cynicism" (Haggis (2006 p.523) because of an academic anxiety to maintain standards and thereby prevent 'dumbing down' of curricula. The implementation of appropriate curricula in science learning may also exist because of the elitist, exclusionary assumptions underpinning academic practice (Boud 2000 cited in Haggis 2006) where academics retain the power and position of the knowledge expert. Such a discourse, however, shifts the responsibility to the academics, when this is perhaps a collective issue. In addition, the dominant epistemological view in the 'hard-sciences' of positivism, assuming that objects can be separated from their observers and where knowledge is treated as a passive, objective reflection of events that have occurred in the past may also prevent the synergy needed between process and product. If we are to deal with process and uncertainty we need an approach to knowledge as doing (present & dynamic) rather than knowledge of something (past & static).

Given these barriers and challenges, is there then a third way which steers an educationally productive path between in this context the extremes of naïve, pure discovery enquiry learning on the one hand, and the hard-line back to basics fundamentalism on the other? Far from being self-evident, the implementation of an appropriate curriculum, is partly hidden from academics themselves (Haggis 2006 p. 530), because the explicit understandings of the discipline and curricula are often left tacit (Ross et al., 2010) and academics even from the same field together will contest disciplinary processes (Haggis 2006). It maybe that academics alone cannot make the tacit explicit. Yet it is they who are best positioned epistemologically to close the gap between importance and performance in curriculum design.

Over 100 years go Dewey called for a closing of the gap between the doing of science and the learning of science. Over 50 years ago Schwab (1962), warned us of the consequences: “if the solution is to divorce concept and method (process) and treat both of them as orthodoxies…the result…will be to surround science with an even greater aura of religious certainty”. More recently, Nobel laureates have cautioned us about the resilience of the unchanged narrative (Weiman 2007, Weiman et al., 2010). What remains clear is that until we close the gap and bring into synergy science learning and the learning of science, we will have neither curriculum coherence nor congruence (Bybee 2003). We now need momentum to overcome this inertia to better prepare our science graduates for a supercomplex world (Barnett 2000). One in which there is real synergy between science learning and learning science so that science answers are understood as contestable, rigorously uncertain and complex.

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