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Linking the experiential, affective and cognitive domains in biology education: a case study – microscopy

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ABSTRACT

A greater emphasis in school curricula on the technology of science would encourage teachers to engage their students more in practical work. This in turn might be expected to improve students' attitudes towards science and enhance cognitive outcomes. The paper presents findings from a study on first-year university students' school experience of, attitudes towards, and knowledge of, microscopy. The findings reinforce the general expectations alluded to above. They also draw attention to the importance of the lower secondary science experience – often a suboptimal one owing to a poor resource base – to the formation of student attitudes and cognitive development with respect to science.

KEYWORDS
Technology (of science); secondary school science; microscopy; attitudes (to science)

Introduction

It is widely regarded as axiomatic in science education that positive classroom learning experiences are conducive to positive attitudes towards, and cognitive gains in, science (Simpson and Oliver 1990; Woolnough 1994; Osborne, Simon, and Collins 2003). The empirical evidence connecting these is, however, not quite as clear-cut. Despite the emphasis over the past couple of decades on inquiry-based approaches to science teaching and learning, conclusive evidence to the effect that such approaches achieve better academic outcomes remains elusive, and studies that indicate a link between this approach and achievement suggest that their findings be treated with caution (Kirschner, Sweller, and Clark 2006; Geier et al. 2008; Wolf and Fraser 2008). The relationship between attitudes and achievement in science is even more obscure (Papanastasiou and Zembylas 2002).

The relationship between the learning experience (experiential domain), attitudes (affective domain) and achievement (cognitive domain) should be easier to elucidate when dealing with the technology of science (largely in the psychomotor domain) rather than with abstract theory (higher cognitive domain). A focus in modern science education curricula is how science works. This invokes both epistemological and technological aspects of the scientific method. The first of these has received a great deal of attention in the literature, principally with reference to scientific thinking (see e.g. Schwartz, Lederman, and Crawford 2004). The technological aspect has received rather less. The profile of technology varies between the sciences. The teaching of high school physics necessarily involves exposing students to a range of technologies both crude (e.g. the ticker-timer) and sophisticated (e.g.

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dataloggers and motion sensors). High school biology presents fewer opportunities for the inclusion of technology; however, units on cells and micro-organisms lend themselves to a technology-intensive approach through their association with microscopy, both the optical and electron versions.

This study targeted university students' general knowledge about microscopy in relation to their secondary school experience and their attitudes towards microscopy. Our working hypothesis was that a positive interrelationship is expected between the quality of the school microscopy experience, attitudes towards microscopy, and knowledge of microscopy as a technology of biological science. A subsidiary hypothesis was that the study of biology at the upper secondary level (senior biology) ought to be conducive to higher evaluations in all three areas. The enhancing effect of senior biology on beginning university students' understanding of scale in diagrammatic representations of cells has already been demonstrated by Vlaardingerbroek, Taylor, and Bale (2014).

Methods

The sample

The cohort enrolled in first-year foundation science at an Australian university was selected for the study on the basis of availability. Typically these students come from a wide range of secondary schools based in small towns across northern NSW and to a lesser extent southern Queensland. Only students who had not engaged in the formal study of biology between high school and their current enrolment were eligible to participate. It should be noted that Biology is the most popular senior science subject with Australian secondary school students (Kennedy, Lyons, and Quinn 2014) and is less often studied alongside any other science. The Stage 6 NSW Biology Curriculum contains a considerable amount of material on cell structure and the technology associated with the study of cells, including light and electron microscopy (Board of Studies New South Wales 2013). For example, 'Students perform a first-hand investigation to gather first-hand information using a light microscope to observe cells in plants and animals and identify nucleus, cytoplasm, cell wall, chloroplast and vacuoles' (26).

The instrument

A data collection instrument was devised by the authors, and was administered in pen-and-paper form in the first week of classes of the 2015 academic year. Students were asked to indicate what year they had completed their high schooling and whether they had studied senior biology for purposes of attaining their HSC (Higher School Certificate). They were then presented with two questions about their high school experience of microscopy. In the first, they were asked to rate their high school experience on a scale between 0 ('You never saw a microscope at high school') to 3 ('You did some practical work either by yourself or in a group which involved the use of a microscope which you personally got to handle') while in the second they were asked to rate the quality of the experience on a scale again between 0 ('Never looked at cells and/or micro-organisms through a microscope while at school') to 3 ('Got a nice clear view of cells and/or micro-organisms under the microscope'). These were followed by two questions targeting their attitudes towards microscopy. The first asked them to evaluate their school microscopy experience in terms of learning about cells and/or micro-organisms on a scale between 0 ('No benefit at all') to 3 ('Very beneficial') while the second asked them to indicate their personal level of interest in microscopy as technology on a scale from 0 ('Not really interested') to 3 ('Very much interested').

The second part was made up of 13 multiple-choice items targeting students' knowledge about microscopy. Items ranged from simple technical issues such as calculating total magnification for an optical microscope to more esoteric topics such as the microtome. The themes covered by the test are given in the 'Results' section below. Students were also invited to make free response comments about their high school microscopy experience in spaces provided.

Analysis

A 'school experience' score between 0 and 6 was derived from the first two items while an 'attitudes towards microscopy' score also between 0 and 6 was arrived at by adding together the second pair of items. Distributions for each of these scores were compared between students who had studied senior biology and those who had not using the χ^2 test which was also used to test for association between the two scores.

A test score out of 13 was arrived at for each student. These were compared between students who had studied senior biology and those who had not using the t-test. Test score distributions were tested for association with school experience and attitudes towards microscopy scores using the t-test or F-test as appropriate. Responses to the test items were analysed by response option for students who had studied senior biology.

Results

A total of 234 duly completed forms were collected. The overwhelming majority of students had attained the Higher School Certificate in 2013 or 2014. One hundred and fifty-five had taken senior biology and 79 had not.

The school experience score was generally high with 135 students (58%) awarding it 6/6 and 51 (22%) awarding it 5/6. Numbers for the lower five scores (0–4) were so low that they were amalgamated. As Table 1 shows, the senior biology experience was associated with a significant increase in this score.

Scores for attitudes to microscopy were more spread out and the 0–3 and 4–6 score ranges were combined to avoid low cell counts. As Table 2 indicates, the senior biology experience was again associated with higher scores.

There was a significant positive association between distributions for the two scales using these amalgamated score ranges, 36% of the sample occupying the cell representing the intersection of a school experience score of 6 and an attitudes towards microscopy score in the range of 4–6 ($\chi^2 = 25.29$, $p < 0.001$).

The mean for the 13 test items was 6.20 (47.7%) with a standard deviation of 1.95 (15.0%). As shown by Table 3, students who had been enrolled in senior biology scored slightly higher than students who had not; recourse to the 1-tailed test is reasonable given that the senior biology experience does not annul the middle-years biology (as part of 'general science') experience but is an additional 'treatment'.

Table 1. School experience ratings and senior biology enrolment at high school.

School experience score	No senior biology	Senior biology	χ^2
0–4	33 (42%)	15 (10%)	
5	17 (22%)	34 (22%)	
6	29 (37%)	106 (68%)	35.39, $p < 0.001$

Table 2. Attitudes to microscopy ratings and senior biology enrolment at high school.

Attitudes to microscopy score	No senior biology	Senior biology	χ^2
0–3	51 (65%)	67 (43%)	
4–6	28 (35%)	88 (57%)	9.52, $p < 0.01$

Table 3. Test scores and senior biology enrolment at high school.

	No senior biology	Senior biology	t
n	79	155	
Mean	5.85	6.37	
SD	2.27	1.74	1.81, $p < 0.05$ (1-tailed)

Table 4. Test scores against school experience ratings.

	School experience score			
	0–4	5	6	*F*
n	48	51	135	
Mean	5.54	5.77	6.59	
SD	2.37	1.78	1.75	7.12, $p < 0.01$

Table 5. Test scores against attitudes towards microscopy ratings.

	Attitudes towards microscopy score		
	0–3	4–6	*t*
n	118	116	
Mean	5.81	6.59	
SD	1.98	1.84	3.09, $p < 0.01$

Table 6. Responses to test items for students who had studied senior biology.

Theme	% correct	Comments
Definition of cover slip	79	
Total magnification by eyepiece × objective lens	77	
Purpose of staining techniques	76	
Meaning of 'resolution'	73	
Century first single-lens microscope made	59	
Why electron microscope so called	49	
Decade first functioning electron microscope	43	
Microscope made using coarse adjustment while on HP (smash the slide)	43	32% opted for 'specimen cannot possibly be brought into focus'
Meaning of 'compound microscope'	39	37% thought it referred to having both coarse and fine focus adjustment knobs
Identification of micrometre as 10^{-6} m	32	28% thought it was 10^{-3} m
Scanning electron microscope (cf. transmission) allows us to see surface of cells	28	38% answered 'molecules'
Magnification capability of school microscope used at Senior Biology level (600×)	23	38% as 100X and 32% as 300X
Recognition of microtome as cutting instrument	19	42% thought it was a graduated scale for measuring size under the microscope and 24% thought it was another name for the fine adjustment knob

As summarised in Tables 4 and 5, test scores for the sample as a whole increased significantly with both the school experience score and the attitudes towards microscopy score.

Table 6 provides details of the responses to test items by students who had studied senior biology. The items are ranked in descending order of the number who selected the correct answer option.

Students who had undergone the senior biology experience appeared to be mostly competent with regard to the use of the coverslip, the calculation of total magnification, the use of staining techniques and the concept of resolution, and knew what century the first single-lens microscope was produced in. Half of them recognised the definition of an electron microscope, and almost the same proportion knew the decade when it was first used. Surprisingly, fewer than half recognised the fact that racking by means of the coarse adjustment knob while on high power may result in the smashing of the slide; this may reflect little prior experience with high-power magnification. Equally surprisingly, fewer than 40% recognised the term 'compound microscope', while only one in three could define the micrometre. Many of them had apparently not encountered the scanning electron microscope and most were not cognisant of the microtome. The fact that fewer than one in four could correctly identify the magnification limit of a standard school microscope is probably related to the anecdotal observation that many teachers restrict their students to the use of medium power to avoid damage to the high-power objective lens. This may involve removing the high-power lenses before giving microscopes to students to use.

Discussion

If our sample is at all representative, Australian middle-years science teachers (most of whom are biology graduates (Harris, Jensz, and Baldwin 2005)) appear to be doing a fair job in introducing lower and middle-secondary students to the world of microscopy with an approval rating of almost 60% (as indicated by school experience scores of 5 and 6/6) from students who had not gone on to study senior biology. It is at this stage that students are taught about the workings of the optical microscope. The experience, brief as it is, appears to stick in students' minds. However, the lower secondary experience of microscopy is not uncommonly marred by a lack of resources, as these comments from students who had not progressed to senior biology bear witness to:

> The microscopes at my high school were of a poor quality, which made it difficult to see.
>
> Microscopes in better condition would have been a big help.
>
> Microscopes in ratio to students was 1:8.

Smaller classes and better equipment at the senior level understandably have positive effects on students' school experience of microscopy, with 90% giving it a rating of 5 or 6/6. Whereas students who had not studied senior biology tendered no positive comments about their high school experience at all, a number of ex-senior biology students did so, typified by the following:

> Very fascinating and enjoyable – fundamental.
>
> It was very interesting seeing cells and micro-organisms under the microscope.
>
> Was fairly sick, enjoyed looking at [micro-]organisms.

There were, nevertheless, caveats expressed, such as the following:

> Would have liked to use microscope by myself, hardly got a turn.
>
> We got to use microscopes a lot but they weren't the most easy microscopes to use.
>
> We didn't know enough about what we were looking at for the experience to be beneficial.
>
> The teachers never really showed us how to use one, thus many of us didn't know what to look for.

Students' attitudes towards microscopy were evenly split between the 0–3 and 4–6 score ranges for the scale. While factors other than the quality of the school experience feed into this, the positive association between the two scales, as well as between the attitude score and the senior biology experience, is suggestive of a high-quality 'hands-on' high school experience being a contributing factor in relation to the development of positive attitudes towards microscopy.

The association between these experiential and affective measures and students' knowledge of microscopy extends this relationship into the cognitive domain. Interestingly, the senior biology experience in isolation did not give students any but the most slender of edges in the test, although this finding was consistent with the study by Vlaardingerbroek, Taylor, and Bale (2014) mentioned earlier. Australian school students are usually introduced to the workings of the optical microscope at lower secondary level, often in the context of Hooke's development of the microscope giving rise to the discovery of cells (ACARA 2010a, 2010b). Students are then expected to recall these when they get to upper secondary school, at which level they are formally introduced to electron microscopy (although many teachers do mention this at the earlier stage as well). Thus many upper secondary teachers may use the microscope as a means to an end in their teaching approach rather than going into the workings of the technology to any appreciable degree, as these comments from students who had gone through senior biology suggest:

> We didn't learn specific things about microscopes, we just used them.
>
> I feel as though my teachers didn't go into enough depth about microscopes.
>
> I have never heard of half this stuff.

Test scores rose significantly with both school experience and attitudes towards microscopy scores. The school experience is often enhanced by the study of biology at senior level, but this study suggests that the quality of the lower secondary experience is of considerable importance in the formation of attitudes and the acquisition of knowledge about microscopy. It will be noted that the practical themes generally make an appearance at the lower secondary science level when students are introduced to the microscope, while a traditional inclusion in school textbooks is the history of the technology.

Conclusion and recommendations

The results we have presented provide evidence for the case that positive classroom experiences in science involving 'hands-on' student engagement (experiential/psychomotor domain) stimulate the formation of positive attitudes towards science (affective domain) and lead to improved knowledge and understanding thereof (cognitive domain) in the context of learning about the technology of science. Whether that in turn translates into a better understanding of theoretical science is another, albeit related, issue. However, we view a working knowledge of the technology of science as an important and underrated objective of science education in its own right. Teachers will teach what the curriculum requires them to teach – especially for examination purposes – and if the curriculum is thin on the technology of science, classroom coverage is likely to be commensurate. We concur with the student who opined that:

> Microscopes are not covered nearly enough in the HSC Bio syllabus.

We would counsel teachers of biology to spend a little more time on the intricacies of the technology involved in revealing the secrets of the cell, especially at the senior level where the cognitive gain with respect to the methods of science in this context appears to be minimal, although the quality of the learning experience and the formation of positive attitudes towards this aspect of the workings of science appear to receive considerable boosts from the study of cell and micro-biology at that level. It is pertinent to note that microscopy lab work is necessarily 'guided' in the sense of being structured rather than of the 'open-ended inquiry' type, given that the former results in more effective learning (Kirschner, Sweller, and Clark 2006).

An issue that this study highlights is the formative potential of lower secondary school science with regard to both attitudes and subsequent cognitive gain. Middle-years science, especially in British-derived school systems where lower and upper secondary schooling tend to occur under the same roof, is often viewed as a chore by subject-specialist science teachers who have to spend a lot of their time teaching 'general science' at the lower levels. Senior biology, senior chemistry and senior physics, owing to their bridging functions to tertiary education, are widely regarded as having far more impact. This study suggests, however, that in the case of at least one area of the technology of science, the junior secondary science experience has a far more enduring impact than would perhaps be envisaged by many practitioners. There is a case here for paying much more attention to the technology as opposed to the theory of science at lower secondary level. Reid and Skryabina (2002), in relation to physics education in Scotland, came to much the same conclusion when they noted that courses which emphasise the 'application-based approach rather than a content-based approach [are] very appealing to pupils' (79).

This suggestion fits in well with the common theme in science education literature of needing to place a greater emphasis on practical work in school science as a means of engaging students (e.g. ACARA (Australian Curriculum and Assessment Reporting Authority) 2010a; Goodrum, Druhan, and Abbs 2011). Australian high school students would appear to agree. In the 'Choosing Science' report (Lyons and Quinn 2010) the principal recommendation by Year 10 students in relation to encouraging more students into Year 11 sciences was to do more practical work. In this context, well-intentioned but time-pressed teachers struggle to cope with the demands of new technologies and an inquiry-oriented curriculum (Gregson 2011). Unfortunately for many students, their experience of science accordingly consists of a body of knowledge to be memorised, rather than a process by which ideas are tested and refined through laboratory experiences (Danaia, Fitzgerald, and McKinnon 2013). A greater focus on the technology of science could give a new direction to the general urge to engage school students in more practical science.

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