CENTRE FOR GLOBAL HIGHER EDUCATION

Centre for Global Higher Education working paper series

Undergraduate students' knowledge outcomes and how these relate to their educational expectations: a longitudinal study of chemistry in two countries

Paul Ashwin, Margaret Blackie, Nicole Pitterson & Reneé Smit

Working paper no. 86
November 2022

UKRI Economic and Social Research Council
UKRI Research England

Published by the Centre for Global Higher Education,
Department of Education, University of Oxford
15 Norham Gardens, Oxford, OX2 6PY
www.researchcghe.org

ISSN 2398-564X

The Centre for Global Higher Education (CGHE) is an international research centre focused on higher education and its future development. Our research aims to inform and improve higher education policy and practice.

CGHE is a research partnership of 10 UK and international universities, funded by the Economic and Social Research Council, with support from Research England.

Undergraduate students’ knowledge outcomes and how these relate to their educational expectations: a longitudinal study of chemistry in two countries

Paul Ashwin, Margaret Blackie, Nicole Pitterson & Reneé Smit

Contents

Undergraduate students’ knowledge outcomes and how these relate to their educational expectations: a longitudinal study of chemistry in two countries

Paul Ashwin, Margaret Blackie, Nicole Pitterson & Reneé Smit

Paul Ashwin is Deputy Director of CGHE and Professor of Higher Education at Lancaster University. Paul’s research is focused on the educational role of higher education. His recent books include *‘Transforming University Education: A Manifesto’* (2020) and *Reflective Teaching in Higher Education* (2015, 2020) written by an international team to support the development of research-informed university teaching. p.ashwin@lancaster.ac.uk

Margaret Blackie is an associate professor in the Centre for Higher Education Research, Teaching and Learning at Rhodes University. Prior to this appointment she taught and researched in organic chemistry for over a decade. Her current research interests are in tertiary science education exploring issues of knowledge building and knower awareness. mags.blackie@ru.ac.za

Nicole Pitterson is an Assistant Professor in the Department of Engineering Education at Virginia Tech. Her research is focused on the design and evaluation of learning environments with specific focus on how to foster and support conceptual understanding of difficult concepts. npitters@vt.edu

Reneé Smit works as a senior lecturer Academic Development in the department of Electrical Engineering at the University of Cape Town, South Africa. Her research interest lies at the intersection of professional education in engineering, the nature of engineering knowledge and the applied philosophy of engineering. The research has implications for educating engineers, but also for collaborative work between practitioners in science and engineering. renee.smit@uct.ac.za

Abstract

In this CGHE working paper, we draw on the outcomes of a major CGHE project: The Understanding Student Knowledge and Agency Project. Based on the data from this project, we examine how students' accounts of the discipline of chemistry in England and South Africa change over the three years of their undergraduate degrees. Based on a longitudinal phenomenographic analysis of 105 interviews with 33 chemistry students over the course of their undergraduate degrees in four institutions, we constituted five qualitatively different ways of describing chemistry. These ranged from describing chemistry as something that happens when things are mixed in a laboratory to a more inclusive account that described chemistry as being able to explain molecular interactions in unfamiliar environments. Most students expressed more inclusive accounts of chemistry by the end of their degrees and the level of change appeared to be related to their educational expectations. These outcomes highlight the importance of understanding the role that disciplinary knowledge plays in student outcomes from higher education and the importance of students understanding their degrees as an educational experience.

Keywords: chemistry, knowledge, phenomenography, higher education outcomes, students

Acknowledgment: This Working Paper is being published by the ESRC/RE Centre for Global Higher Education, funded by the U.K. Economic and Social Research Council (award numbers ES/M010082/1, ES/M010082/2 and ES/T014768/1).

Introduction

How the outcomes from higher education for students should be measured and thought about is an area of contest and debate (see Carson 2021, Monteiro et al. 2021). Whilst some argue that these can be thought about generically in terms of the graduate attributes developed by students or graduate salaries (see Fryer 2021 for a summary and critique), others argue that the outcomes of higher education are particular to the study of particular subjects and bodies of knowledge (for example, see Wald & Harland 2019). This second way of understanding outcomes is focused on how higher education changes the ways in which students see the world by giving them access to a body of knowledge that changes their understanding of the world (Bowden and Marton 1998). In order for this way of understanding the outcomes from higher education for students to be developed further, there is a need to have a sense of the ways in which students' engagement with particular bodies of knowledge change their understanding of the world. In this paper, we draw on the CGHE project 'Understanding Knowledge and Student Agency' to examine how the understanding of students' studying chemistry changed over the course of their undergraduate degrees and how this relates to their educational expectations of their role as students.

Students' relations to knowledge in higher education

It has long been established, from a variety of research perspectives, that there are disciplinary differences in teaching and learning (for example, Donald 1986, Becher & Trowler, 2001; Trowler, Saunders & Bamber, 2012). There is a growing sense that the processes and outcomes of learning vary between disciplines, as students engage with different kinds of knowledge (Entwistle, 2018). However, whilst much is known about the principles of curriculum design and pedagogy that support high quality student learning in higher education (Ashwin et al. 2020), less is known about the ways in which particular forms of knowledge are positioned in higher education curricula, the ways in which students come to engage with these forms of knowledge, and the transformative relations that are established between students and knowledge.

Donald (1986) explored four levels at which disciplinary differences could be expected to occur: The nature of the concepts used, the logical structure of the discipline, in the criteria for truth adopted and the methods used. Whilst Donald's work focused on apparently objective differences between disciplines, the body of the literature that the current paper contributes to focuses on students' understanding of their subjects of studies. This focus helps to highlight the ways in which students can be supported to develop their understanding of disciplinary knowledge because it focuses on how this knowledge appears to students rather than how this knowledge appears in the curriculum. To use Ashwin's (2014) terminology it focuses on 'knowledge-as-student-understanding' rather than 'knowledge-as-curriculum' or 'knowledge-as-research'.

Research examining students' understanding of their subjects of study have generally taken a phenomenographic perspective (Marton & Booth 1997). This is because phenomenography focuses on the qualitative variation in the ways that people experience particular phenomena. Table 1 sets out the structure of students' accounts from phenomenographic studies examining a number of different disciplines. Whilst the studies vary in the number of accounts of each discipline produced, in each case the variation can be argued to fall into three main stages (van Rossum and Hamer 2010). First, there is a least-inclusive basic account that focuses only on the immediately visible aspects of the discipline. Second there is a 'watershed' account in which students focus on a structured body of knowledge. This is a key shift because engagement with structured bodies of knowledge is the key focus of higher education (Ashwin 2020). Third, there is a most inclusive account in which students see this body of knowledge in a wider context. What all of the structures of variation have in common is that they are based on different configurations of the discipline, the world and the student.

Table 1: Structure of students' accounts of different disciplines from phenomenographic studies

Discipline	Studies	Least inclusive account	'Watershed' account	Most Inclusive account
Accountancy	Sin et al. 2012	Routine work	Meaningful work	Moral work
Geography	Bradbeer et al. 2004	General world	Structured into parts	Interactions
Geoscience	Stokes 2011	Composition of earth – the earth	Processes – interacting systems	Relations earth and society
Law	Reid et al. 2006	Content	System	Extension of self
Mathematics	Crawford et al. 1994, 1998; Wood et al. 2012	Numbers	Models	Approach to life
Music	Reid 2001	Instrument	Meaning	Communicating
Sociology	Ashwin et al. 2014	Developing opinions	Study of society	Relations self, people and societies

One aspect of students' accounts of their disciplines that is less examined is how students' accounts change over time. This is because the existing research has tended to take a snapshot of how students describe their relations to their disciplines at particular times. Students' changing understanding over time was examined in the study looking at students accounts of sociology (Ashwin et al. 2014) and has been undertaken into students' accounts of particular concepts (for example see Dahlgren 1989; Trumper 1998), research into students' epistemological development (for example see Baxter Magolda 1992, 2004), research into students' conceptions of learning (for example van Rossum and Hamer 2010) and research into students' learning patterns (for example see Donche et al. 2010, Neilsen 2013; Richardson 2013).

In this study we were interested in examining the variation in students' accounts of chemistry and how student accounts changed over the course of their undergraduate degree. Research into students' understanding of chemistry knowledge has primarily focused on their understanding of particular chemical concepts (Johnstone 1982, 2006; Ebenezer and Erickson 1996; Case and Fraser 1999; Ebenezer and Fraser 2001; Taber 2019). This focus on individual concepts can be seen to mirror the dominant approach to teaching chemistry: teaching chemistry as a 'collection of somewhat isolated topics' (Sevian and Talanquer, 2014). More recently, there has been a shift to focus on the development of 'chemical thinking in students (Sevian and Talanquer, 2014; Sjöström and Talanquer, 2018; Talanquer et al., 2020) as well as examinations of how students developed a more general understanding of science (Flaherty, 2020).

However, there have been very few longitudinal studies that have examined how students' understanding of chemistry develops over time and these have tended to focus on school children (for example, see Øyehaug and Holt, 2013). Mathias (1980) followed a small group of science students, including chemistry students, through their undergraduate course. However, this study examined how students approached their studies rather than their understanding of chemistry. The current study sought to build on the work in chemistry education research by examining whether factors in students' educational environment were related to changes in students' understanding of chemistry. Previous studies of changes to students' understanding of their discipline suggests that these were more likely when students saw their degree course as involving personal change (Ashwin et al. 2016) and experienced a supportive relationships with their teachers (Ashwin et al. 2017).

In summary, the purpose of the current paper is to examine how variation in students' accounts of chemistry change over the course of their degrees and how these changes relate to students' understanding of their educational responsibilities.

Methodology

The research project

The data from this project comes from the CGHE project: Understanding Knowledge and Student Agency. This project researched undergraduate degrees of chemistry and chemical engineering in two universities each in England, in South Africa and in the USA. This paper reports on data from the longitudinal study of chemistry students we tracked through the three years of their degree in England and South Africa. We excluded the student data from the USA because the greater level of choice in the modules that students studied meant that most of the students were not studying a chemistry degree that was comparable with that studied by students in England and South Africa.

The students were drawn from a larger self-selecting sample of 66 students (31 England, 35 South Africa) who were interviewed in their first year. From these students, we selected a smaller sample of 40 (20 from each country) students that reflected the diversity of the degree programmes in terms of ethnicity and gender. We have only included students in the analysis for this paper if they had completed an interview in their third year of studies and at least one interview in their first and second year. There were 33 students who had sufficient data to be included in the analysis for this paper, 19 from England and 14 from South Africa.

All institutions and participants are anonymised in line with the ethical approval granted by the lead institution in the research (Reference Number FL15035). Ethical approval was also obtained as required at each of the research sites. The English and South African universities in this research were given pseudonyms based on chemical elements to protect anonymity. These are:

- England - Erbium University and Europium University
- South Africa - Samarium University and Sodium University

Students have also been given pseudonyms reflecting the cultural diversity of the cohorts.

It is important to note that the South African and English Chemistry degrees have slightly different structures. Due to the earlier specialization in the English education system, the curriculum in the first year in the English chemistry degrees has more in common with the second year of the South African degrees. Whilst in England students register for a three year Bachelor of Science degree with honours (or a four year Masters' degree), in South Africa students register for a three year Bachelor of Science degree and then can apply for a stand-alone one year Honours degree.

Semi-structured interviews followed a common protocol with questions covering students' background, route into university, study practices, understanding of disciplinary knowledge, assessment experiences, views on diversity and future aspirations. The methodology of this larger project owes a considerable debt to a previous project looking at students' engagement with knowledge in sociology (see McLean et al. 2018).

Data analysis

In this paper we have analysed our interview data using a phenomenographic approach (Marton and Booth 1997). All authors of the paper worked on the analysis, which was focused on the qualitative variation in the ways in which the students' described their understanding of chemistry as a subject. Categories of description were formed by iterating between individual analysis of the interviews and group discussions of the outcomes of this analysis. We examined the qualitative variation in the meaning of students' accounts of chemistry and the logical relations between each of the categories of description. The categories were formed and reformed by moving between these different forms of examination with the aim of constituting a hierarchy of empirically grounded and logically consistent outcome space which captured the qualitative variation between each of the categories of description. This hierarchy is understood to be inclusive, with the later categories including the earlier categories (Marton and Booth 1997; Åkerlind 2005).

It should be noted that it is the variation between the categories, rather than the categories themselves, that is the focus in phenomenography and that the outcomes from phenomenographic studies are based on the variation across all of the interview transcripts rather than a categorisation of each individual in the study (Marton and Booth 1997; Åkerlind 2005). Thus, in line with the inclusive structure of the hierarchy, any one interview may contain more than one of the categories of description constituted in this study. To reflect this, we discuss students' accounts in terms of their alignment with each category of description rather than suggesting their accounts 'contain' different categories of description.

When examining how students' accounts of chemistry changed between their first and final interviews, individuals were assigned to the highest category of description that was evident in their interview. It is important to recognise that this is a use of phenomenographic outcome space rather than a part of the phenomenographic study. Finally, the claim being made about the outcome space is that it is constituted in the relation between the researchers and the data (Marton & Booth 1997). Thus, it is accepted that it is not the only possible outcome that could be constituted from the data. What is important is that the categories can be argued for convincingly on the basis of the data (see Åkerlind 2005 for an analysis of the different approaches taken in phenomenographic studies).

In forming the categories, we were aware of Ashworth and Lucas's (1998) criticism that phenomenography tends to overly focus on authorised accounts rather than the meaning the particular phenomena have for students. In analysing the data, we attempted to bracket our understandings of chemistry. It is worth noting that the phenomenographic method is very rarely employed in the chemistry education literature and, when it is, it tends to focus on experience of learning environments rather than interrogating conceptions of knowledge (Chopra et al. 2017; Tekane et al. 2020).

Outcomes

Based on our analysis of the interview data we constituted five different ways of accounting for the discipline of chemistry:

Category 1: Chemistry happens when you mix things in the laboratory

Category 2: Chemistry is about seeing chemical reactions

Category 3: Chemistry is about the learning about molecular interactions

Category 4: Chemistry is about explaining molecular interactions

Category 5: Chemistry is about explaining molecular interactions in unfamiliar situations in the world.

These different ways of accounting for chemistry involved different relations between the student, the world and the discipline of chemistry. Table 3 sets out the outcome space as a whole and how the different categories of description fit within this. The structural aspects focus on the changes in what is in the foreground and background of the accounts. These shift from chemistry being about *doing* things, to chemistry being about *seeing* certain things, to chemistry being *explaining* certain things. The referential aspects focus on the meaning of chemistry which shifts from chemistry referring to *chemical reactions* to chemistry referring to *molecular interactions* to chemistry referring to *unknown situations in the world*. These structural and referential aspects come together to form each category of description: under category 1 chemistry is about doing chemical reactions whereas, under category 5, chemistry is about explaining things that are happening in new situations in the world. The watershed shift comes in category 3 where students shift to understanding chemistry as about chemical reactions to seeing chemistry as about molecular interactions

We now set out each of the categories in turn and in doing so focus on giving a richer sense of the variation between the categories

Table 2: The referential and structural aspects of the categories of description for students' accounts of chemistry

	Referential Aspects		
	Chemical reactions	Molecular Interactions	World
Structural Aspects			
Doing	Category 1		
Seeing	Category 2	Category 3	
Explaining		Category 4	Category 5

Category 1: Chemistry happens you mix things in the laboratory

Students' accounts which aligned with this category described chemistry in a way that focused on doing chemistry to create particular kinds of chemical reaction. Chemistry was discussed as a fairly nebulous subject and in terms of what happens in a laboratory in a very broad way, which was external to the student:

For me, I think it's how you can have two different elements and they can make, literally, like a hundred different things just by adding two together or adding… It just fascinates me how something so small and how you don't really need to do anything but something amazing can happen. I think that to me is like quite unique (Henry, Europium, Year 1).

A lot of educated putting things together and proving that it works. I think to be fair, our lab environments are very controlled. We have got step-by-step processes, we're not playing around with anything (Steffi, Sodium University, Year 2).

Category 2: Chemistry is about seeing chemical reactions

In student accounts aligned with this category of description, there was a shift away from doing chemistry to chemistry being about seeing the world in terms of chemical reactions. Students whose accounts aligned with this category of description often referenced the US TV series ‘Breaking Bad’ and the idea that chemistry is about change, although chemistry was still talked about as something that was external to the student:

It’s lots of things, really, but boiling it down to simple, it’s elements and what they do. How they work in the world, and how they react. What affects what. I don’t know, really. It’s quite hard to explain, isn’t it? Yes, it’s just how and why things happen the way they do. Generally how, and looking at it (Denise, Erbium University, Year 1).

Well, I would say it’s just studying everything that- studying just how things change, that’s probably the easiest way. The study of just yes, probably change, because that is what it’s about. Change and changing things for what you want them for or changing things to see what would happen or why things change (Hayden, Europium University, Year 1).

Category 3: Chemistry is about the learning about molecular interactions

In student accounts aligned with this category of description, chemistry was described in terms of learning about molecular interactions rather than just seeing chemical reactions. Chemistry was also positioned as something that was internal to the student that they were engaged in rather than something that was external to them. This can be seen as a watershed because it is the category in which students accounts of chemistry begin to focus on the structure of the body of knowledge of the discipline through a focus on understanding the causality of submicro molecular interactions.

Okay, so looking at molecules, elements, how they interact. Maybe how you can use them to make other molecules and things. And just learning about the, I don’t know, their characteristics and things (Ming, Samarium University, Year 2).

Virtually everything you study is about a reaction taking place or something changing on a molecular level or whatever it is – changing state (Dale, Erbium University, Year 2).

Category 4: Chemistry is about explaining molecular interactions

In student accounts aligned with this category of description, the emphasis was on being able to explain molecular interactions rather than simply learning about them. In these accounts chemistry was positioned as a way of using an understanding of molecular interactions in order to explain the world and was positioned as something that was internal to the student:

Chemistry is, well it's basically, let's say, the knowledge of how everything is formed. How everything, or physical properties of the universe, how it forms and how it's put together, how it's taken apart. Knowing how it happens, what happens with it, why it happens (Scarlet, Sodium University, Year 3).

Chemistry is the science of understanding life at the molecular level. It's about understanding and trying to improve life at the molecular level. Making maybe alterations to those tiny things that are not visible to our eyes and stuff so that we can maybe get desired results (Mawonde, Samarium, Year 2).

Category 5: Chemistry is about explaining molecular interactions in unfamiliar situations in the world

Student accounts aligned with this category of description, positioned chemistry in terms of the explanation of molecular interactions in unfamiliar or new situations. Thus, rather than simply explaining things in situations that were already familiar, this category of description foregrounds the capacity to act on the world and develop explanations in new situations. In accounts aligned with this category of description, students' understanding of chemistry informs their action and gives them agency:

It's a neat way of explaining how things work. It allows you to fine-tune processes and think about things in ways that people may not have thought of before. Especially with environmental issues popping up, it's going to be more useful in finding ways around things like fossil fuels (Demi, Erbium University, Year 3).

Now we've been trying to see if you bring two molecules that you've never ever seen before, you apply all of those different rules together, you'll form a new molecule. If you followed the rules properly, and then you did it in real life, you would get the same answer. So I think it's useful for if you want to design anything, any new material (David, Erbium, Year 3).

Changes to students' accounts of chemistry over time

Table 3 shows that 29 of the 33 students' accounts of chemistry appeared to be more inclusive in their third year than their initial interview (the dark shaded cells). In students initial interviews, none of their accounts aligned with categories 4 or 5, whereas in the third year interview over a third of their accounts did. In five cases the account of chemistry appeared to be the same in terms of the outcome space (the unshaded cells). In no cases did the student's account appeared to be less inclusive in their third year than their initial interview (the light shaded cells).

Table 3: Relations between the category of chemistry that students expressed in their first and final interviews

	3rd Year highest category					
Initial category[1]	1	2	3	4	5	Total
1	1	2	9	3	1	16
2		1	4	6	1	12
3			3	1	1	5
4				0	0	0
5					0	0
Total	1	3	16	10	3	33

1. In 30 cases this was an interview in their first year, in 3 cases this was in their second year

We will now shift to examine the relationships between students' accounts of chemistry and changes to their account of chemistry to a number of aspects of their educational experiences. In examining these relationships, we acknowledge the limited size of our sample. This examination is intended to offer an insight into the factors that appeared to shape students' understanding of chemistry but in further studies are needed.

Tables 4 and 5 show that we did not find any clear institutional or national differences in students' accounts of chemistry. Whilst Erbium University had the student with the largest change in the category of description that their account aligned with, it also had the most students who had no change, Table 5 shows that one English (Erbium) and one South Africa University (Samarium) had the greatest range in the most inclusive category of description aligned with students' accounts of chemistry in their final year interview. Whilst it is noticeable that no student studying in South Africa had accounts of Chemistry aligned with Category 5, this is likely to be due the differences in degree structure mentioned earlier with students in South Africa having another year's study before reaching honours.

Table 4: Changes to the most inclusive category of description aligned with students' accounts of chemistry first and final interview by their university

University	No change	+1 category	+2 categories	+3 categories	+4 categories	Total
Erbium	3	0	5	1	1	10
Europium	1	2	4	2	0	9
Samarium	1	3	3	0	0	7
Sodium	0	1	4	2	0	7

Table 5: The most inclusive category of description aligned with students' accounts of chemistry in students' final interview by their university

University	Category 1	Category 2	Category 3	Category 4	Category 5	Total
Erbium	0	2	6	0	3	10
Europium	0	0	7	2	0	9
Samarium	1	2	2	2	0	7
Sodium	0	0	1	6	0	7

We examined whether the changes in students' accounts of chemistry were related to other aspects of their educational experience. There appeared to be two aspects of the students' experiences of education that related to the extent to which students' accounts changed over the three years and the most inclusive category expressed in their interview. Both of these aspects were related to what students expected of themselves as students. The first aspect concerned whether students expected that they should do what was required on their degree programme (-C) or whether they expressed expecting that they would change as a result of their education (+C). It is important to be clear that students who foregrounded the expectation to do what was required on their programme did sometimes talk about being changed by their studies. The distinction being made is that they did not express this as an expectation of their role as students. We illustrate this difference with quotations from Matodzi (-C) and Mawonde (+C). These quotations are useful because Matodzi positions himself as an active learner but, in contrast to Mawonde, there is not a sense that he expects to be changed by his studies.

It's being an active learner, one who not only goes to lectures and studies but I need to have an inquisitive mind and learn more about my work for myself
Matodzi, Year 2, Chemistry, Samarium University

A university degree is valuable because it allows you to think in a way that a person who doesn't have a degree wouldn't think... All these parts in your brain that wouldn't

be at any time unlocked or unleashed or whatever, universities allows you to reach those parts
Mawonde, Year 2, Chemistry, Samarium University

The second aspect of students' expectations was whether they expected to decide what aspects of their education to engage with (-E) or whether they expected to fully engage with the educational environment provided by their institution (+E). In the illustrative quotations below both students are focused on their individual expectations. However, Hayden (-E) is very clear that it is up to him to decide which aspects of his educational environment he draws on, whereas Sivuyile (+E) foregrounds an expectation that he fully engages with the educational environment provided by the University.

I suppose educationally, it's down to me. They can't drag me to a table and make me work, or drag me into university and make me sit through lectures. They've not got any kind of responsibility, or right, to a certain degree. Because if I want a day off, I can have a day off. I've paid for it. That's the way I see it.
Hayden Year 2, Chemistry, Europium University

My responsibility as a student is to create a network and allow myself to communicate and make use of all the structures and facilities that the university has made available for me to better myself
Sivuyile Year 1, Chemistry, Sodium University

Table 6 shows that, across our sample, students who expressed their educational expectations in terms of doing what was required in their education through deciding which aspects of their education they engaged with (-C-E) tended to have less change in the way they talked about chemistry than other students. Table 7 shows that these students did not talk about chemistry beyond the way captured under Category of Description 3. Without either a sense that they expected to change through their studies (+C-E) or they should engage fully with the educational environment provided by their institution (-C+E) or both (+C+E), they appeared to gain less in terms of their engagement with knowledge and develop less inclusive accounts than other students.

Table 6: Changes to the most inclusive category of description aligned with students' accounts of chemistry in their first and final interview by their account of their educational expectations

	No change	**+1 category**	**+2 categories**	**+3 categories**	**+4 categories**	**Total**
-C-E	5	3	3	0	0	11
-C+E	0	2	9	2	0	13
+C-E	0	0	1	2	1	4
+C+E	0	1	3	1	0	5

-C= Expectation to do what is required on their degree programme

+C = Expectation to change myself through their degree programme

-E = Expectation to decide which aspects of their education they engage with

+E = Expectation to engage fully with the educational environment provided by their university

Table 7: The most inclusive category of description aligned with students' accounts of chemistry in their final interview by their account of their educational expectations

	Category 1	Category 2	Category 3	Category 4	Category 5	Total
-C-E	1	3	7	0	0	11
-C+E	0	0	7	5	1	13
+C-E	0	0	0	3	1	4
+C+E	0	0	2	2	1	5

-C= Expectation to do what is required on their degree programme
+C = Expectation to change myself through their degree programme
-E = Expectation to decide which aspects of their education they engage with
+E = Expectation to engage fully with the educational environment provided by their university

Discussion

In discussing the significance of our outcomes, we focus on three aspects of the study: the relations between the structure of variation in students' accounts of chemistry and those in other disciplines, how the outcomes of the study relates to previous studies of students' understanding of chemistry and the significance of the ways in which changes to students' accounts of chemistry appeared to be related to their expectations of their educational relationship with their programme and university.

The first aspect is how the structure of the variation in students' accounts of chemistry relate to the other subjects that were discussed earlier. For chemistry the outcome space develops from a less inclusive category of description focused on the doing of chemistry to a watershed category of description focused on learning about molecular interactions to a most inclusive category of description focused on explaining in these interactions in unfamiliar situations. In common with the studies from other disciplines (Crawford et al. 1994, 1998; Reid 2001; Bradbeer et al. 2004; Reid et al. 2006; Stokes 2011; Sin et al. 2012; Wood et al. 2012; Ashwin et al. 2014), there is a shift from knowledge being external to the student and based on it most obvious features, to knowledge being placed in a disciplinary structure and then a shift to students developing a personal relationship to knowledge. It is important to be clear that whilst students can have a personal relationship to knowledge prior to knowledge being placed in a disciplinary structure what is important in the second shift is develop a personal relationship with knowledge that has been placed within this disciplinary structure.

Whilst the different disciplines share this overall general shift, in terms of the way in which this relationship with knowledge within a disciplinary structure becomes personal is more like geography (Bradbeer et al. 2004) and geoscience (Stokes 2011) where the way of engaging with the world is more important than the way in which the self is implicated by the structure of knowledge as is the case with accountancy (Sin et al. 2012); law (Reid et al. 2006); mathematics (Crawford et al. 1994, 1998; Wood et al. 2012); music (Reid 2001) and sociology (Ashwin et al. 2014). This difference is worthy of further exploration to consider whether it reflects differences in knowledge-as-research, knowledge-as-curriculum, or knowledge-as-student-understanding (Ashwin 2014) or whether it is reflective of differences in the focus of the studies of these different disciplinary areas.

In terms of the understanding that the current study offers of students' accounts of engaging with knowledge in chemistry it offers something between the very general ways of understanding students' accounts of knowledge (for example Baxter Magolda 1992, 2004) or approaching scientific reasoning (for example Flaherty 2020) and studies of students' understanding of particular chemical concepts (Johnstone 1982; Ebenezer and Erickson 1996; Case and Fraser 1999; Ebenezer and Fraser 2001; Taber 2019). The outcomes are aligned with recent research on the development of chemical thinking (Sevian and Talanquer, 2014; Sjöström and Talanquer, 2018; Talanquer et al., 2020) and reflect the shift from the macro to the sub micro level that is a key feature of the chemistry educational literature

(Johnstone 1982). However, these outcomes focus on the structure of students' explanations of chemical phenomena whereas the current study gives an insight into students' accounts of the discipline of chemistry and how they position themselves in relation to it.

Finally, the current study shows how changes in students' accounts of chemistry appear to relate to their educational expectations. It appears that where students expect to change through their studies themselves and/or to fully engage with their educational environment then they are more likely to develop more inclusive understandings of chemistry. Whilst it may seem strange that students tended to only adopt one of these positions, it makes sense that to develop a richer understanding of chemistry students either need to be focused on how they change themselves through chemistry or they need to commit to fully engaging with their educational environment. These are two different ways of expressing an expectation of engaging in an educational relationship with their studies and at least one of these is needed to develop a richer understanding of their discipline. Whilst this general outcome would be expected given previous research (for example, see Entwistle 2018), the ways in which students educational expectations of their role as students is related to changes in their understanding of a particular discipline is new and echoes findings about changes in students' understanding of sociology and how they perceive their education environment (Ashwin et al. 2016; 2017). It again highlights that students need to understand that a key part of their university experience is to enter into an educational relationship with their degree programme. It is important to be clear that we are not suggesting that it is solely up to students to be clear about their educational expectations. Rather, the implications of this observation are related to the ways in which degree programmes help to shape students educational expectations rather than to suggest we should 'blame the student' for not understanding their educational responsibilities.

Conclusion

In conclusion, this paper contributes to a growing body of literature that highlights the importance of students' engagement with particular bodies of disciplinary and professional knowledge when considering the outcomes of higher education for students. The study shows that students' developing understanding of chemistry contributes to a way of thinking about how to engage with the world and is related to their educational expectations of their role as students. This adds further weight to arguments that considering the outcomes of higher education in generic terms obscures both what is central to what students' gain through their engagement with knowledge and the importance of students being committed to changing themselves through an educational relationship with their institution if they are to maximise the likelihood of them making these gains.

Acknowledgements

This paper is from the Centre for Global Higher Education (CGHE) Understanding Knowledge, Curriculum and Student Agency Project. We acknowledge the contribution of the other project team members: Jenni Case, Jan McArthur, Ashish Agrawal, Janja Komljenovic, Kayleigh Rosewell, Alaa Abdalla, and Benjamin Goldschneider. The support of the Economic and Social Research Council, the Office for Students and Research England (grant reference: ES/M010082/1) and National Research Foundation, South Africa (grant reference: 105856) are gratefully acknowledged along with support from CGHE.

References

Åkerlind, G.S (2005). Variation and commonality in phenomenographic research methods. *Higher Education Research & Development*, 24: 321-334.

Ashworth. P. and Lucas, U. (1998). What is the 'world' of phenomenography? *Scandinavian Journal of Educational Research*, 42: 415-431.

Ashwin, P. (2020). *Transforming University Education: A Manifesto*. London: Bloomsbury.

Ashwin, P. (2014) Knowledge, curriculum and student understanding. *Higher Education* 67 : 3-126.

Ashwin, P., Abbas, A., & McLean, M. (2014). How do students' accounts of sociology change over the course of their undergraduate degrees? *Higher Education*, 67: 219-234.

Ashwin, P., Abbas, A., & McLean, M. (2016). Conceptualising transformative undergraduate experiences: A phenomenographic exploration of students' personal projects. *British Educational Research Journal*, *42*(6), 962-977.

Ashwin, P., Abbas, A., & McLean, M. (2017). How does completing a dissertation transform undergraduate students' understandings of disciplinary knowledge? *Assessment & Evaluation in Higher Education*, *42*(4), 517-530.

Ashwin, P., Boud, D., Calkins, S., Coate, K., Hallett, F., Light, G., Luckett, K., MacLaren I., Mårtensson, K., McArthur, J., McCune, V., McLean, M., & Tooher, M. (2020). *Reflective Teaching in Higher Education*. Second Edition. London: Bloomsbury

Baillie, C., Bowden, J. and Meyer, J. (2013). Threshold capabilities: threshold concepts and knowledge capability linked through variation theory. *Higher Education 65*: 227-246.

Baxter-Magolda, M. (1992). *Knowing and reasoning in college.* San Francisco: Jossey-Bass Publishers.

Baxter-Magolda, M. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist,* 19: 31-42.

Becher, T. and Trowler, P. (2001). *Academic Tribes and Territories: Intellectual Enquiry and the Cultures of Disciplines.* Second Edition. Buckingham: Society for Research into Higher Education and Open University Press.

Bowden, J. and Marton, F. (1998). *The University of Learning: Beyond quality and competence in higher education.* London: Kogan Page.

Bradbeer, J., Healey, M. and Kneale. P. (2004). Undergraduate geographers' understandings of geography, learning and teaching: a phenomenographic study. *Journal of Geography in Higher Education*, 28: 17-34.

Carson, J. (2021). Re-thinking a Bachelor of Arts for the 21st-Century precariat. *Studies in Higher Education*, 1-11. DOI: 10.1080/03075079.2021.1916906.

Case, J. and Fraser, D. (1999). An investigation into chemical engineering students' understanding of moles and the use of concrete activities to promote conceptual change. *International Journal of Science Education*, 21: 1237–1249**.**

Chopra, I., O'Connor, J., Pancho, R., Chrzanowski, M. & Sandi-Urena, S. (2017). Reform in a general chemistry laboratory: how do students experience change in the instructional approach? *Chemistry Education Research And Practice,* 18**,** 113-126.

Crawford, K., Gordon, S., Nicholas, J., and Prosser, M. (1994).Conceptions of mathematics and how it is learned: The perspectives of students entering university. *Learning and Instruction*, 4: 331-345.

Crawford, K., Gordon, S., Nicholas, J., and Prosser, M. (1998). Qualitatively different experiences of learning mathematics at university. Learning and Instruction, 8: 455-468.

Dahlgren, L. (1989). Fragments of an economic *habitus*: conceptions of economic phenomena in freshman and seniors. *European Journal of Psychology of Education*, 4: 547-558.

Donald, J. (1986). Knowledge and the university curriculum. *Higher Education*, *15*(3), 267-282.

Donche, V., Coertjens, L., and Van Petegem, P. (2010). Learning pattern development throughout higher education: a longitudinal study. *Learning and Individual Differences,* 20: 256-259.

Ebenezer, J. and Erickson, G. (1996). Chemistry students' conceptions of solubility: a phenomenography. *Science Education*, 80: 181–201.

Ebenezer, J. and Fraser, D. (2001). First year chemical engineering students' conceptions of energy in solution processes: phenomenographic categories for common knowledge construction. Science Education, 85: 509-535.

Entwistle, N. (2018). *Student Learning and Academic Understanding: A Research Perspective with Implications for Teaching*. London: Academic Press.

Flaherty, A. (2020). Investigating perceptions of the structure and development of scientific knowledge in the context of a transformed organic chemistry lecture course. *Chemistry Education Research And Practice,* 21**,** 570-581.

Fryer, T. (2021). Conceptualising graduate outcomes with critical realism. *Higher Education Policy.* https://doi.org/10.1057/s41307-021-00232-2

Johnstone, A. (1982). Macro-And Micro-Chemistry. *School Science Review* 64, 377–379.

Johnstone, A. (2006). Chemical education research in Glasgow in perspective. *Chemistry Education Research and Practice*, *7*(2), 49-63.

Marton, F. and Booth, S. (1997). *Learning and Awareness*. Mahwah, New Jersey, Lawrence Erlbaum Associates.

Mathias, H. (1980). Science students' approaches to learning. *Higher Education*, *9:* 39-51.

McLean, M., Abbas, A. and Ashwin, P. (2018) *How Powerful Knowledge Disrupts Inequality: Reconceptualising Quality in Undergraduate Education.* London: Bloomsbury.

Monteiro, S., Almeida, L., Gomes, C., & Sinval, J. (2020). Employability profiles of higher education graduates: a person-oriented approach. *Studies in higher education*, 1-14. DOI: 10.1080/03075079.2020.1761785.

Neilsen, T. (2013). Changes in BSc Business Administration and Psychology students' learning styles over one, two and three years of study. *Studies in Educational Evaluation*, 39: 41–48.

Øyehaug, A. & Holt, A. (2013). Students' understanding of the nature of matter and chemical reactions: a longitudinal study of conceptual restructuring. *Chemistry Education Research And Practice,* 14**,** 450-467.

Reid, A. (2001). Variation in the ways that instrumental and vocal students experience learning music. *Music Education Research*, 3: 25-40.

Reid, A., Nagarajan, V. and Dortins, E. (2006). The experience of becoming a legal professional. *Higher Education Research & Development*, 25: 85-99.

Reid, A. Petocz, P. and Taylor, P. (2009). Business students' conceptions of sustainability. *Sustainability*, 1: 662-675.

Richardson, J. (2013). Research issues in evaluating learning pattern development in higher education. *Learning and Individual Differences*, 39: 66-70.

Sevian, H. & Talanquer, V. (2014). Rethinking chemistry: a learning progression on chemical thinking. *Chemistry Education Research And Practice,* 15**,** 10-23.

Sin, S., Reid, A. and Jones, A. (2012). An exploration of students' conceptions of accounting work. *Accounting Education: An International Journal*, 21: 323-340.

Sjöström, J. & Talanquer, V. (2018). Eco-Reflexive chemical thinking and action. *Current Opinion In Green And Sustainable Chemistry,* 13**,** 16-20.

Stokes, A. (2011). A phenomenographic approach to investigating students' conceptions of geoscience as an academic discipline. In A. Feig and A. Stokes (Eds.) Qualitative enquiry in *Geoscience education research: Geological Society of America Special paper 474 (*pp.23-35). Boulder, Colorado: Geological Society of America.

Taber, K. (2019). *The Nature Of The Chemical Concept: Re-Constructing Chemical Knowledge In Teaching And Learning*. London: Royal Society Of Chemistry.

Talanquer, V., Bucat, R., Tasker, R. & Mahaffy, P. G. 2020. Lessons From A Pandemic: Educating For Complexity, Change, Uncertainty, Vulnerability, And Resilience. *Journal Of Chemical Education,* 97**,** 2696-2700.

Tekane, R., Pilcher, L. A. & Potgieter, M. (2020). Blended learning in a second year organic chemistry class: students' perceptions and preferences of the learning support. *Chemistry Education Research and Practice*, *21*(1), 24-36.

Trowler, P., Saunders, M., and Bamber, V. (Eds.). (2012). *Tribes and territories in the 21st century: Rethinking the significance of disciplines in higher education*. London: Routledge.

Trumper, R. (1998). A longitudinal study of physics students' conceptions of energy in pre-service training for high school teachers. Journal of Science Education and Technology, 7: 311-318.

van Rossum, E. and Hamer, R. (2010). *The meaning of learning and knowing*. Rotterdam: SensePublishers.

Wald, N., & Harland, T. (2019). Graduate attributes frameworks or powerful knowledge? *Journal of Higher Education Policy and Management*, *41*(4), 361-374.

Wood, L., Petocz, P. and Reid, A. (2012). *Becoming a mathematician: an international perspective.* Dordrecht: Springer.