Higher Education (2023) 86:1065–1080
https://doi.org/10.1007/s10734-022-00962-1

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

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Accepted: 3 November 2022 / Published online: 23 November 2022

Abstract

Are the ways of engaging with the world that students develop through higher education particular to bodies of knowledge they study? In this article, we examine how students' accounts of the discipline of chemistry in England and South Africa changed 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 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 experiences. In contrast to approaches that emphasise the generic student outcomes from higher education, these findings highlight the importance of recognising the distinctive outcomes that students gain from their engagement with particular bodies of disciplinary knowledge. It further highlights the importance of students understanding their degrees as an educational experience that requires them to commit to engaging with these bodies of knowledge.

Keywords Chemistry · Knowledge · Phenomenography · Higher education outcomes · Students

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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., 2022). 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 engagement with higher education changes the ways in which students see the world by giving them access to a structured body of knowledge that changes their sense of who they are and what they can do in the world (Ashwin, 2020; Bowden & Marton, 1998). In order to deepen understanding of how students develop new ways of thinking and doing through their engagement with their degree programme (see McCune & Hounsell, 2005; Anderson & Hounsell, 2007; McCune et al., 2021), there is a need to examine the ways of seeing that are developed through particular bodies of knowledge and to examine how these change over the course of students' degrees. In this article, we report on a longitudinal study of how students' understanding of chemistry changed over the course of their undergraduate degrees and the aspects of their educational experiences that appeared to support their engagement with this body of knowledge.

How does engagement with academic knowledge change students' understanding of the world and themselves?

It has long been established, from a variety of research perspectives, that there are disciplinary differences in teaching and learning (for example, Becher & Trowler, 2001; Donald, 1986; Trowler et al., 2012). There is a growing sense that the processes and outcomes of learning vary between disciplines, as students engage with different kinds of academic 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 how students' understanding of particular bodies of knowledge change over their degrees and how these new understandings change their understanding of the world and themselves. Developing such understanding is important in order to gain a sense of how students are transformed by engagement with these bodies of knowledge (Ashwin, 2020). This requires investigating how students' understand the bodies of knowledge that make up particular disciplines, professions and subject areas and how this understanding changes over time. To use Ashwin's (2014) terminology, it involves gaining a sense of how students' transform 'knowledge-as-curriculum' into 'knowledge-as-student-understanding'.

Much of the research that has examined students' understanding of their subjects of study has 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 & Hamer, 2010)

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

even though not all of the studies cited in Table 1 used these terms. 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) and the watershed account unlocks an understanding of the disciplinary logic and organisation of the structured body of knowledge. 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.

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 a particular moment in their educational experience. Gaining a sense of how these accounts change over time is important in order to examine the impact that students' educational experiences have on their changing understanding of these structured bodies of knowledge. This 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 & 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 (for example, Case & Fraser, 1999; Ebenezer & Erickson, 1996; Ebenezer & Fraser, 2001; Johnstone, 1982, 2006; 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 & Talanquer, 2014). More recently, there has been a shift to focus on the development of chemical thinking in students (Sevian & Talanquer, 2014; Sjöström & 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 & 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 suggest that these were more likely when students saw their degree course as involving personal change (Ashwin et al., 2016) and experienced supportive relationships with their teachers (Ashwin et al., 2017).

In summary, the purpose of the current article is to examine how variation in students' accounts of chemistry changed over the course of their degrees and how these changes were related to students' educational experiences.

Methodology

The research project

The larger project on which this article is based examined students' experiences of undergraduate degrees in chemistry and chemical engineering in six universities: two each in England, in South Africa and in the USA. 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).

This article reports on data from the longitudinal study of chemistry students we tracked through the three years of their degree in England and South Africa. This is because the students from England and South Africa were studying chemistry curricula that were very similar whereas the greater level of choice in modules for students studying in the USA meant that there was much less consistency in the chemistry knowledge that they engaged with during the course of their degrees.

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 as follows:

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

It is important to note that whilst the knowledge in the curriculum was very similar, the South African and English Chemistry degrees had slightly different structures. Due to the earlier specialisation 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.

Data generation and analysis

The data for this article is based on interviews with a self-selecting sample of 40 students (20 from each country) that study chemistry undertaken once a year over the three years of their undergraduate degree. The sample reflected the diversity of the degree programmes in terms of ethnicity and gender. We have only included students in the analysis for this article 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 article, 19 from England and 14 from South Africa.

The semi-structured interviews with the students normally lasted between 60 and 90 min. They 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. In the interviews, students were asked about how they would explain chemistry to a non-chemist and how they drew on their knowledge of chemistry in their everyday lives. Although the analysis drew on the full interview transcripts, it was in response to these questions that students particularly focused on outlining their views of chemistry.

We analysed our interview data using a phenomenographic approach (Marton & Booth, 1997). Phenomenography is a way of analysing data that seeks to capture the variation in the way that a group of people experience a phenomenon. Rather than applying theory to the data or using a priori categories to structure the analysis, a phenomenographic approach seeks to establish all the different ways of seeing that phenomenon that are expressed in the data and to place them in a logical and inclusive hierarchical structure (Åkerlind, 2005; Marton & Booth, 1997). It should be noted 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 (Åkerlind, 2005; Marton & 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. Initially, we worked individually to identify all of the different ways of understanding chemistry that could be identified across the transcripts. We then worked collectively to explore which of the different ways of understanding chemistry appeared to be qualitatively different and what the logical relations were between these qualitatively different accounts of chemistry.

The process led to the forming of 'categories of description' that expressed the qualitative variation between the different accounts of chemistry in an inclusive hierarchy, in which the later categories of description include the earlier categories (Åkerlind, 2005; Marton & Booth, 1997). 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.

Within a phenomenographic approach, 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. This involved putting aside our previous understanding of chemistry and focusing on the accounts of chemistry expressed in the interviews. This process was greatly assisted by working collectively in a group whose knowledge of chemistry ranged from academic expertise to high school level chemistry, as it allowed robust conversations to take place about the extent to which the outcome space was supported by the interview data. Overall, this means that the outcome space presented is based on many discussions of the best way of expressing the variation in accounts of chemistry identified in the interviews that captured the logical relations between the different categories and was supported by students' accounts in their interviews.

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. We also examined how students' accounts of chemistry and the changes to their accounts of chemistry appeared to relate to their educational experiences in terms of the institution that they studied at and their accounts of these experiences. It is important to recognise that both of these aspects of the analysis involve the use of the phenomenographic outcome space rather than being a part of our phenomenographic analysis. 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 things are mixed in a laboratory
- Category 2: chemistry is seeing chemical reactions
- Category 3: chemistry is learning about molecular interactions
- Category 4: chemistry is explaining molecular interactions
- Category 5: chemistry is 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 2 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.

Category 1: chemistry happens when things are mixed in a 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. Students discussed chemistry in quite general terms and tended to focus on what happened when chemistry was 'done' in a laboratory. The sense given was that chemistry was something that was external to the student as it happened separately to the student rather than it being something that the student was necessarily involved in.

> 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

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: chemistry happens when things are mixed in a laboratory		
Seeing	Category 2: chemistry is seeing chemical reactions	Category 3: chemistry is learning about molecular interactions	
Explaining		Category 4: chemistry is explaining molecular interactions	Category 5: chemistry is explaining molecular interactions in unfamiliar situations in the world

> 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 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. Chemistry was still talked about as something that was separate and external to the student rather than it being something that the student was directly involved in.

> 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 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. In contrast to the first two categories, chemistry was positioned as something that students were directly engaged in rather than something that was being done or organised by other people. 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 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 explaining molecular interactions

In student accounts aligned with this category of description, the emphasis was on the student being able to explain molecular interactions rather than simply learning about them. In these accounts, chemistry was positioned as a way of the student using an understanding of molecular interactions in order to explain the world. Thus, in this category, there was the first sense that the students' engagement with chemistry was something that had relevance to the world.

> 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 University, Year 2).

Category 5: chemistry is 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 in 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). Importantly, in their third year interview, 29 out of the 33 students' accounts of chemistry were aligned with the watershed category of description or a more inclusive category. This shows that, by their final year, nearly all students gave an account of chemistry based on a disciplinary way of viewing the world.

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

	Third 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

Relations between students' accounts of chemistry and their educational experiences

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 further studies are needed in order to substantiate these insights.

Tables 4 and 5 show that we did not find any clear institutional or national differences in students' accounts of chemistry. In Table 4, 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. In Table 5, it is notable that one English (Erbium) and one South African university (Samarium) had students who gave accounts of chemistry that were below the 'watershed' category that indicated a

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	1	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

disciplinary way of engaging with chemistry. Given the self-selecting nature of our sample, it is not possible to discern whether this reflects differences in the education offered by these institutions.

Whilst we did not find any clear evidence of institutional differences, we did find evidence of a relationship between changes in students' accounts of chemistry and other aspects of their educational experiences. The extent to which students' accounts changed over the three years and the most inclusive category expressed in their third year interview appeared to be related to two aspects of what students expected of themselves as students.

The first aspect concerned whether students foregrounded doing what was required as a student or whether they foregrounded the importance of being changed by their education. 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 which of these they positioned as the key element of being a student. We illustrate this difference with quotations from Matodzi and Mawonde. These quotations are useful because Matodzi positions himself as an 'active learner' but there is not a sense that he expects to be changed by his studies. This is in contrast to Mawonde who explicitly foregrounds the importance of being 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 choose which aspects of their education to engage with or whether they expected to engage fully with educational environment provided by their institution. In the illustrative quotations below, both students are focused on their individual expectations. However, Hayden is very clear that it is up to him to decide which aspects of his educational environment he draws on, whereas Sivuyile 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.

Bringing these two elements together across our sample, the 11 students who expressed their educational expectations in terms of doing what was required in their education through choosing which aspects of their education they engaged with tended to have less change in the way they talked about chemistry than the other 22 students and did not talk about chemistry beyond the way captured under category of description 3. This means they appeared to gain less in terms of their engagement with knowledge and develop less inclusive accounts of chemistry than students who expected to change and/or expected to fully engage with their educational environment.

Discussion

There are three significant aspects of the outcomes of this study: how it offers a holistic sense of the relations to the world that students develop through studying chemistry, how it highlights the distinctiveness of the outcomes of students engagement with particular bodies of knowledge through higher education, and how it emphasises the importance of students being committed to engaging with these bodies of knowledge if they are to benefit fully from their engagement in higher education.

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 (Case & Fraser, 1999; Ebenezer & Erickson, 1996; Ebenezer & Fraser, 2001; Johnstone, 1982; Taber, 2019). The outcomes are aligned with recent research on the development of chemical thinking (Sevian & Talanquer, 2014; Sjöström & Talanquer, 2018; Talanquer et al., 2020) and reflect the shift from the macro to the molecular level that is a key feature of the chemistry educational literature (Johnstone, 1982). However, whilst these previous studies focus on the structure of students' explanations of chemical phenomena, the current study gives an insight into students' accounts of the discipline of chemistry and how they position themselves in relation to it. In doing so, the outcomes from this study give a more holistic sense of the variation in the relations with the world that students develop through their engagement with chemistry.

This highlights how students' relationship with the world changes as it is mediated by their knowledge of chemistry. In the outcome space, 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 in a similar way to studies from other disciplines (Ashwin et al., 2014; Bradbeer et al., 2004; Crawford et al., 1994, 1998; Reid, 2001; Reid et al., 2006; Sin et al., 2012; Stokes, 2011; Wood et al., 2012). 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 to develop a personal relationship with knowledge that has been placed within this disciplinary structure. In this way, the outcome space captures how students' changing sense of what they can do in the world through their engagement with this knowledge (Ashwin, 2020). What is particularly important is that these changes appear to distinctive to particular bodies of knowledge rather than generic.

Despite this distinctiveness, it is possible to see similarities between the shifts in some subjects. For example, the shift in chemistry is more similar to geography (Bradbeer et al., 2004) and geoscience (Stokes, 2011) where the way of engaging with the world is key. This is in contrast to 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) where the way in which the self is implicated by the structure of knowledge is also important. 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.

Finally, the current study shows how changes in students' accounts of chemistry appear to relate to their educational experiences. 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. This suggests that to fully benefit from higher education, students need to be committed to engaging with the body of knowledge of chemistry offered through their educational environment. This is similar to findings of students' studying sociology (Ashwin et al., 2016, 2017) and highlights the need for institutions to consider how to support students in developing an educational relationship with the bodies of knowledge they are studying. It also highlights that part of the problem with the focus on generic higher education outcomes for students is that it can conceal that the successful achievement of these outcomes is dependent on students' committed engagement to the particular bodies of knowledge they encounter through higher education (Anderson & Hounsell, 2007; McCune & Hounsell, 2005; McCune et al., 2021).

Conclusion

In conclusion, this article 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 how these outcomes vary with the bodies of knowledge that students engage with in their degree programmes. It also obscures the importance of students being committed to engaging with these bodies of knowledge if they are to fully benefit from their engagement in higher education.

Acknowledgements This article 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. We also acknowledge the insightful comments of two anonymous reviewers that help to sharpen the analysis and argument in this article.

Funding The support of the Economic and Social Research Council and Research England (grant reference: ES/M010082/1) and the National Research Foundation, South Africa (grant reference: 105856), is gratefully acknowledged along with support from CGHE. The data reported in this article will be deposited with the UK Data Service once the research is complete.

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