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ARTICLE

Building capabilities in chemistry education: happiness and discomfort through philosophical dialogue in chemistry

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Much attention is given to student satisfaction in higher education, driven in the UK by accountability mechanisms such as the National Student Survey (NSS) and the Teaching Excellence Framework (TEF). However satisfaction is both limited and limiting, depending on students' expectations and often associated with the avoidance of difficulty and discomfort. A more appropriate outcome for higher education is well-being and ability to flourish. This paper identifies a gap in undergraduate chemistry education. *Talking Chemistry* created an extracurricular space for undergraduate chemistry students to build capabilities to flourish through philosophical dialogue about chemistry. It involved 25 undergraduates over one academic year (2018-19). Drawing on ethnographic observations, questionnaires and in-depth semi-structured individual interviews, we argue that philosophical dialogue in undergraduate chemistry studies opens up opportunities for discomfort that can contribute to students' capabilities to achieve happiness and well-being by challenging students to think about their subject in new ways. Philosophical dialogue is a missing component of chemistry education, and we present a model for introducing it into higher education.

Introduction

Philosophy in chemistry education

Chemistry is a science concerned with "molecules that are of the right size to directly affect human life" (Kovak, 2015) and as a result raises ethical, political and epistemological questions. These questions require both chemical knowledge and a philosophical approach, yet few science students experience philosophy in their degree or teacher education programmes. The philosophy of chemistry (rather than philosophy of science more broadly) is an emerging field concerned with questions about what chemistry is; how it differs from other ways of knowing; the methods and structures central to chemical practice; and how chemists justify knowledge claims (Scerri, 2000; Erduran, 2001). In contrast to countries where philosophy is compulsory in pre-higher education, it is possible to be a chemist without formally learning or doing philosophy in the UK. Indeed, education in the philosophy of science rarely features explicitly in chemistry education at secondary or tertiary level (Erduran & Mugaloglu, 2014; Höttecke & Silva, 2011). While some scientists question the utility of philosophy to their discipline (cf. Wolpert, 2000), Scerri (2001) argues that philosophy of chemistry provides a deeper understanding of chemistry subject matter, and that it can therefore be of use to chemistry educators in explaining what it is that chemists do, and why. Teachers exposed to philosophy of chemistry have been found to develop more sophisticated views of chemistry and chemists (Sendur, Polat & Kazanci, 2017). This study explored the effects of introducing undergraduates to the philosophy of chemistry through an extracurricular education and outreach project, during which they carried out philosophical workshops about chemistry with peers and school pupils.

Bencze, Bowen & Alsop (2006) argue that philosophy of science is needed in undergraduate programmes to promote views of science that are more aligned with the authentic practices of science. The limitations of a chemical education without philosophy have been identified as: "likely to contribute to chemical illiteracy: a form of alienation where, not fully understanding how knowledge growth occurs in chemistry, students invent mysteries to explain the material world" (Erduran, 2001, p. 589). Philosophy has an important contribution to make to chemical literacy because it contributes to students' knowledge and understanding of the nature of chemistry. By participating in philosophical dialogue, students develop tools for deliberating and thinking critically; they ask questions, identify assumptions, reflect on their positions, justify claims and explore alternative perspectives. Doing this enables them to better understand and use chemistry in their lives. Furthermore, by thinking with others, they come to better understand their position in response to the questions being asked.

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In the context of science more broadly, Na & Song (2014) attribute two different causes of alienation of relevance to chemistry in higher education (HE): a) the difficulty of the subject; and b) its disconnection from students' everyday experiences. The notion of science being 'important but not for me' is a recurrent finding in science education research (cf. Jenkins and Nelson, 2005; Archer et al, 2013). Engaging students in good chemistry education must include philosophical inquiry as "it needs to satisfy curiosity of the world around them as well as engage them in meaningful dialogue around the construction of scientific knowledge, ideas and processes" (Burgh & Nichols, 2012, p.1052). In contrast to didactic pedagogies (Aydin, 2015), philosophical dialogue through a community of inquiry can be used to address the reported disconnection between chemistry and students by putting their knowledge and questions at the heart of the learning process.

Doing philosophy of chemistry through a community of inquiry

The community of inquiry is a pedagogical approach based on scientific inquiry (Dewey, 2007; Peirce, 1960), in which all are dedicated to the use of like procedures to reach common goals. The community of inquiry requires students to investigate questions or problems themselves, rather than simply learning the refined end products of inquiry (Dewey, 2007) through direct instruction. This is not to dismiss direct teaching approaches – they too have a valuable role to play. They are simply not the approaches used in this project, in which we aimed to provide opportunities for students to explore their own philosophical questions in chemistry. While the community of inquiry has its origins in science, it was adopted by Lipman (2003) in a Philosophy for Children (P4C) programme, which was created in response to concerns about undergraduates being poorly prepared to think critically. The community of inquiry is therefore a pedagogical approach that links philosophy and science in educational contexts, and allows for the exploration of questions that cut across disciplinary boundaries. This approach to education as inquiry involves students exploring (often their own) philosophical questions through collective dialogue, meaning that what they learn is aligned with their interest, rather than a history of ideas in the philosophy of chemistry. The community of inquiry has been used widely in primary schools (cf. Gorard et al., 2015; Topping & Trickey, 2007; Trickey and Topping, 2004). While the community of inquiry has been used to explore philosophical questions about science at the secondary age range (Sprod, 1998; Dunlop, Clarke & McKelvey-Martin, 2018), it has not to our knowledge been used in HE. In secondary education, it has been found that the community of inquiry enables pupils to exercise choice and control over learning, and to connect science with their prior knowledge and interests by examining how knowledge is gained in science; thus addressing the problem of alienation (Na & Song, 2014 and Erduran, 2001). However, in doing so, some pupils report discomfort with uncertainty and lack of resolution of philosophical questions, and the personal challenge they feel when they change their position in response to a question (Dunlop et al., 2018). Furthermore, the community of inquiry is an approach that contrasts with what pupils typically experience in formal science education, potentially causing dissatisfaction.

Beyond satisfaction: discomfort and discontent

Much attention is given to student satisfaction in HE (Elwick & Cannizzaro, 2017). In the UK, such attention is amplified by accountability mechanisms, such as the National Student Survey (NSS), the Teaching Excellence Framework (TEF) and competition-oriented, performance-based league tables partially derived from these. However satisfaction is limited and limiting; it is dependent on undergraduates' expectations and often associated with the avoidance of difficulty and discomfort. Elwick & Cannizzaro (2017) distinguish between satisfaction and happiness. They contrast happiness as a sense of direction towards possessing what it is worth desiring and having in life with satisfaction as a consumerist concept, representing the difference between undergraduates' consumer expectations and experiences. Dean & Gibbs (2015) describe the different focus in terms of 'happier' students being more concerned with how they engage with experiences (a more active approach) and 'more satisfied' students being concerned with how things were done to them (a more passive approach). Some studies even suggest that students express satisfaction with teachers who challenge them least (Emery et al., 2003). Elwick & Cannizzaro (2017) argue - in line with social constructivist approaches to learning - that "well-being, flourishing and a more meaningful understanding of happiness can only be garnered through some level of unhappiness or discontent" (p.210). Or put differently, by undergraduates being drawn out of their comfort zone. Confronting unhappiness or discontent therefore allows students to develop critical awareness and to think about and address issues that they confront - activities that ultimately contribute to a well-lived life (Roberts, 2013).

Theoretical framework: capabilities approach

The capabilities approach (Sen, 2009; Nussbaum, 2011; Walker. 2005) is a way of understanding and evaluating social - including educational - arrangements, in terms of the freedoms people have to do and be what they value. It draws on Aristotelian notions of flourishing, with a specific focus on happiness rather than satisfaction. The capabilities approach holds that the question "what is each person able to do and to be?" (Nussbaum, 2011, p.18) is key to the evaluation of well-being because it draws attention to the freedom that each - not the average or total - person has to do things that are of value to them. The capabilities approach distinguishes between 'functioning' (doing or being) and capability (freedom to do or to be), taking the position that systems - including education systems - should concentrate on capability rather than functioning because the former honours the choices that people have reason to value (Nussbaum, 2011). In a chemistry

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context, a 'functioning' might be making a chemistry-related decision (Nahum et al., 2009), and the capability is the freedom and informed capacity they have to make that decision. The capabilities approach therefore values not only what individuals are able to do, but also the freedom they have to act. The capabilities approach has been under-explored in education, despite the role that it can perform in developing what students are able and free to do (Saito, 2003), not to mention expanding the possibilities of what people may value and the paths they might take through life (Wood and Deprez, 2012, p. 471). This study explores whether philosophical dialogue in chemistry can contribute to students' capabilities.

Nussbaum distinguishes between internal capabilities and combined capabilities, with the former described as the traits or abilities within a person that have been developed through interactions between social, economic, familial and political environments (Nussbaum, 2011, p.21). Combined capabilities are described as a combination of internal capabilities and the freedoms and opportunities they have as a result of the social, political and economic environment. While it is not possible to develop combined capabilities without also developing internal capabilities, the converse is possible: it is possible to develop internal capabilities without opportunities to exercise them (Nussbaum, 2011). Walker (2005) considers pedagogy through the lens of capabilities, arguing that the aim of educators should be develop curriculum and pedagogies that best enhance students' capabilities, and by extension, well-being (p.116). Drawing on research literature, as well as her students' voices, Walker has developed an ideal-theoretical list of capabilities (Figure 1).

[Figure 1]

These ideal-theoretical capabilities are used as a framework for this study, to understand how chemistry students developed their capabilities - both in terms of what they are able to do, and the freedom they have to do it - through philosophical dialogue. In adopting Walker's lens, this study moves beyond a narrow focus on transferring knowledge or promoting student satisfaction. This is because, for the capabilities approach, it is important to consider all dimensions that contribute to human flourishing. Our hypothesis was that using the community of inquiry approach in chemistry education and outreach would contribute to the development of students' capabilities.

Project description: *Talking Chemistry*

Talking Chemistry was an extracurricular programme open to second year undergraduates. It had several aims: a) to introduce students to philosophical dialogue; b) to create connections between philosophy and chemistry; and c) to help them develop and facilitate philosophical dialogue-based workshops in secondary schools with young people aged 11-14. The purpose of *Talking Chemistry* was to develop university students' capabilities in chemistry, education and philosophy. The students who participated were a self-selecting group: no credit or other incentive was provided; all activities took place outside timetabled classes; and the students were not assessed. The sample is therefore comprised of a self-selecting group of undergraduates who were interested in doing philosophy at the outset. In this study, we use 'students' to refer to undergraduates, and 'pupils' to refer to young people in schools.

Philosophical dialogue is taken to mean discussion modelled on Socratic questioning in which a facilitator uses oral questions and questioning as an educational tool (Mitchell, 2006). The aim is to elucidate students' positions in relation to philosophical questions and to identify the assumptions, reasoning and values underpinning their views. In doing so, it promotes collective reflection and discussion through a community of inquiry, with a view to both arriving at the most reasonable answer and identifying pertinent further questions (Lipman, 2003; Peirce, 1960). Teaching approaches in Talking Chemistry drew on philosophical methods (Daly, 2010) and well-established strategies in philosophy education (Lewis and Chandley, 2009; Worley, 2011) for responding to philosophical questions. Philosophical questions are defined as those "whose answers are in principle open to informed, rational, and honest disagreement…", and which require reasoning to be answered (Floridi, 2013, p. 195). A focus on philosophical questions rather than on the teaching philosophy of chemistry was used because our focus was to promote reflection and discussion about how chemical knowledge is created and used, and critical thinking about students' own views of chemistry, rather than teaching about the history of ideas.

An overview of Talking Chemistry is provided in Table 1. It consisted of two parts: learning to do philosophical dialogue in chemistry (part 1), and outreach work in philosophy, chemistry and education (part 2). Part 1 consisted of two workshops. The first workshop introduced students to philosophical questioning and dialogue, while the second focused on introducing students to strategies for facilitating dialogue in chemistry education and outreach. Part 2 (outreach) followed the workshops and students were invited to put their learning into action by planning and facilitating philosophical inquiries in schools and with their peers.

The approach presented in Table 1 was used because we know from research on learning that students need to have new approaches modelled, and to given opportunities to practice new learning (Rosenshine, 2012). During the planning meetings, students were able to create and test philosophical questions, discussing their ideas with the tutor to better understand the nature of philosophical inquiry about science and the role chemical knowledge plays in such inquiries.

We know that doing philosophy with children in schools can raise attainment (Gorard et al., 2015), and improve pupils' scientific reasoning skills (Sprod, 1998), and that school pupils

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have positive perceptions of doing philosophy in science contexts (Dunlop et al., 2018). Enabling undergraduates to practice their philosophical facilitation in an education and outreach setting therefore presented potential mutual benefits for undergraduate students and school pupils.

[Table 1]

During part 2, students designed three philosophical inquiry workshops: Alien Adventures on Twin Earth; Better Brains, Better Bodies and One Planet Philosophy Loft. Selected resources prepared by the students can be found in appendices. These included opportunities for pupils to: create and discuss philosophical questions about chemistry; examine their understanding of chemical concepts (appendix 1); explore philosophical questions in relation to a chosen topic (appendices 2 and 3); identify criteria when making decisions about chemistry (appendix 4); and to discuss relevant thought experiments (appendix 5).

Table 2 captures how *Talking Chemistry* attempted to develop the capabilities identified by Walker as important for happiness and well-being in HE.

[Table 2]

Research questions

Chemistry education literature identifies the potential contribution that philosophy can make to both chemistry and chemistry education, and the contribution that philosophy can make to chemistry education has been discussed at secondary and tertiary levels (Scerri, 2001; Aydin, 2015; Sendur et al., 2017). The educational approach taken in *Talking Chemistry* was novel in that it applied an experiential approach (i.e. the community of inquiry) to doing philosophy. This meant practicing, rather than learning about, philosophy. It also attempted to understand students' experiences not in terms of how satisfied they felt with *Talking Chemistry*, but in terms of how it helped them to develop capabilities through their participation in a workshop and their application of learning to a chemistry education outreach initiative. The main research questions were:

1) What are undergraduate students' experiences of philosophical dialogue in chemistry?
2) How, if at all, can experiencing and leading philosophical dialogue in chemistry outreach foster undergraduate students' capabilities?

Methodology

Research was conducted in line with BERA 's[1] ethical guidelines for educational research (BERA, 2018); ethical approval was obtained from the relevant (Education) departmental ethics committee; and voluntary informed consent was obtained from participants. Fieldwork in two schools took place with teachers' permissions between September 2018 and June 2019. Data collection took place with undergraduates pre- and post-workshop, as well as at the end of the project, with ethnographic observation notes made throughout.

Participants

During Part 1 (learning to do philosophical dialogue), a total of 25 second year undergraduates were involved. They were invited by email or lecture shout out by a member of staff in their department. There were no selection criteria other than year group, and studying Chemistry, Education or Philosophy. Participating students were enrolled in programmes of study in Chemistry (n=22), Natural Sciences (n=1), Philosophy (n=1) and Education (n=1). None of the students were participating in initial teacher education, and only the Philosophy and Education students had been exposed to Philosophy during their degree programme. All 25 completed the pre- and post-questionnaires. These 25 students were invited to participate in outreach. Completion of Part 1 of the project was a pre-requisite for participating in the outreach.

During part 2 (outreach), a total of 11 undergraduates participated from Chemistry (n=10) and Education (n=1) departments. Interviews were conducted after all outreach had taken place. All eleven were invited to participate in interviews, and a total of six students were interviewed. The low uptake of interviews is likely to reflect the time of year they were conducted (end of term, coinciding with the university assessment period).

Research design

An exploratory design was used because so few studies of this nature exist, and the focus was on producing insights into a new approach in chemistry in higher education. For part 1, a pre- and post-workshop questionnaire was used to determine the impact of the workshops on students' responses to philosophy in chemistry. For part 2, interviews were used to understand students'

[1] British Educational Research Association

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experiences of the project as a whole, including the outreach activities.

Data collection

Part 1: Questionnaires to find out students' responses to philosophical dialogue in chemistry

A questionnaire was designed to be used before and after the Talking Chemistry workshops to look for changes in undergraduate students' responses to philosophy in chemistry. Students were asked to report their confidence in, and perceptions of, chemistry and philosophy on a short, minimally intrusive questionnaire designed by the research team for this project. The questionnaire contained 10 Likert-type items (Table 3) and open-ended items about what they learnt, how they learnt it, and their other comments on the project. The questionnaire asked for students' indicative responses to chemistry (items 2, 7, 9), how they relate chemistry to philosophy (items 1, 3, 5 and 6) and students' confidence to communicate (items 4, 8 and 10). Our hypothesis was that there would be few changes in responses to the items about chemistry given the nature of the cohort and the activity (a voluntary, extracurricular outreach project), and more changes in responses to philosophy and to communication (talking, disagreeing, asking questions).

[Table 3]

The sample of 25 is small, but meaningful in the sense that it is the size of a typical class or seminar group in which teaching happens, giving the study ecological validity. Due to the use of ordinal data and small sample size, data was not approximated as interval data and inferential statistical tests were not conducted. Instead, questionnaire data was used to generate a "sophisticated description" (White & Gorard, 2017, p. 63) of students' confidence and perceptions before and after the workshops. Since the aim of this study was not to generate statistical-probabilistic generalizability, but to provide a rich, exploratory description of what effects a novel approach to philosophical dialogue in chemistry has on students, investigation at this level is appropriate.

Part 2: Interviews to find out the extent to which philosophical dialogue develops students' capabilities

At the end of the year, undergraduate students (n=11) who had been involved in the school workshops were invited to participate in in-depth individual semi-structured interviews designed to probe the extent to which students fostered capabilities through their involvement in *Talking Chemistry* (appendix 6). Students were asked about their expectations, motivations and choices relating to their participation in the project, the outcomes they had experienced, how this related to their values, and about the extent to which the project helped them develop their capabilities. Interviews lasted approximately half an hour and were carried out by a member of the research team who had not been directly involved in the design and delivery of the project. Six students participated in the interviews. Interviews were then transcribed and imported into NVivo 12 for analysis using Walker's (2005) ideal-theoretical capabilities for higher education.

Data analysis

Qualitative data were analysed using a deductive approach to thematic coding, which drew on Walker's ideal-theoretical capabilities for HE. Walker argues that a qualitative approach is important in evaluation of capabilities because of the need to include the voices of students, staff and others involved in the (shared) educational experience. The analytical approach was devised and refined during reflexive discussions drawing on the interview data, ethnographic observations and literature on capabilities and happiness in HE. Two members of the project team undertook the analysis, involving data familiarisation, coding and refinement of themes derived from capabilities approach. The themes used in the coding of the data were derived from Walker: practical reason, educational resilience, knowledge and imagination, learning disposition, social relations and social networks, respect, dignity and recognition, emotional integrity and bodily integrity. In the results section (below), we explain how these themes were applied during coding. Given the interpretive approach, multiple coders were used to come to a shared understanding of the meaning of the data from different perspectives (design and delivery of the project, and data collection) rather than to calculate inter-rater reliability. Although a small sample of students participated in the interviews, the insights gained are important in understanding the development of capabilities through philosophical dialogue about chemistry in a community of inquiry education and outreach context.

Results

Part 1: What are undergraduate students' experiences of doing philosophical dialogue in chemistry?

Undergraduate students' experiences of philosophical dialogue in Chemistry were studied using a questionnaire applied before and after the Talking Chemistry workshops. Prior to the workshops, undergraduates reported positive feelings about engagement and curiosity about chemistry and reported feeling less confident in their understanding of how chemists create knowledge, how to analyse chemical concepts, and how talk about ethical issues in chemistry.

Changes in confidence in, and perceptions of, chemistry and philosophy after the workshops are presented in Table 4 and displayed graphically in Figure 2.

[Table 4]

[Figure 2]

Following *Talking Chemistry*, an additional 80% of undergraduates stated that they agreed or strongly agreed

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that they understood how philosophy and chemistry relate to each other. Undergraduates expressed increased confidence in response to the prospect of talking about how chemists create knowledge and ethical issues in chemistry; as well as analysing concepts in chemistry and expressing disagreement. For example, an additional 24% either agreed or strongly agreed that they felt confident talking about how chemists create knowledge after participating in *Talking Chemistry*, while an additional 28% strongly agreed that they felt confident talking about ethical issues in chemistry. Complementing the latter finding, an additional 24% either agreed or strongly agreed that they felt confident analysing concepts in chemistry, while an additional 16% strongly agreed that they felt confident expressing disagreement.

Perhaps unsurprisingly, given the enthusiastic nature of the cohort, negligible changes were observed in undergraduates' engagement with chemistry; confidence talking about chemistry; curiosity about chemistry and the extent to which they have a say in what they learn in chemistry.

In the open comments section (Table 5), students reported what they learnt about the connections between philosophy and chemistry, and reflected on how they had learnt it.

While caution should be taken when interpreting these findings due to the small sample size (n = 25), open question responses indicated that the undergraduates found philosophical inquiry about chemistry refreshing, interesting and engaging, and that they particularly valued the participatory discussions and opportunities to think about chemistry differently. Furthermore, several respondents enthusiastically suggested that philosophical dialogue should become a mandatory part of their degree.

[Table 5]

Part 2: How, if at all, can experiencing and leading philosophical dialogue in chemistry outreach foster undergraduate students' capabilities?

Following the initial inquiry workshops, eleven undergraduates continued with the chemical education outreach, designing and facilitating philosophical inquiries in secondary schools. Six undergraduates subsequently participated semi-structured, in-depth interviews, which aimed to explore whether the workshops and schools' outreach had helped them to cultivate their capabilities. Findings from these interviews and non-participant observation are presented below, with Walker's ideal-theoretical capabilities acting as an organising framework. All students are second year undergraduates (5 in Chemistry and 1 in Education). Pseudonyms are used to attribute quotes.

Developing capabilities: Practical Reason

Exercising practical reason involves making choices that are based on well-informed, critical and reflective judgements. Instances whereby students discussed thinking critically during *Talking Chemistry* were coded under this theme.

Undergraduates reported that *Talking Chemistry* had enabled them to become better at forming arguments in response to questions that are often closed to debate in chemistry education.

> **Jonathan:** *…this has definitely been a boost in that because… we've been shown all these different methods of tackling, like, an ethical question, that's given me more knowledge about how to do that… it wasn't sort of trying to figure out the right answer. It was trying to actually think, 'How can you tackle this question?*

In focusing on the quality of argumentation rather than on identifying singular, correct answers, philosophical dialogue has the potential to bring students' voices into conversations about chemistry in a new and liberating way. In opening a space for students to think about how to construct and defend an argument, undergraduates valued thinking their own, rather than others', thoughts. Furthermore, it was suggested that the benefits of engaging in philosophical dialogue extended beyond chemistry education.

> **Andrew:** *I don't think that it's a sort of, direct science and chemistry benefit. It's more of a sort of, like, a broad benefit to developing their ability to think, which sort of benefits them across the board.*

Undergraduates described how engaging in philosophical dialogue permitted them to consider and, when appropriate, challenge alternative perspectives in a non-confrontational manner. Robert, for example, described becoming more confident about challenging others, as well as doing so in a respectful manner:

> **Robert:** *We got better at seeing the links and asking questions…not provocative questions, but questions that would provoke an answer…by the end, we knew that we could challenge what we said. And I think I would be less scared to do that now. And, 'cause I sort of feel like I've got a better manner of doing it, that presents it in a, like, non-confrontational way. And, obviously, you do sometimes need to challenge other people's thoughts, so, I think I'll definitely take that forward.*

This suggests that students became more conscious of how to deliberate productively during *Talking Chemistry*. Their ability to formulate critical questions was partly fostered by the experiential approach taken during workshops, when undergraduates reflected on how dialogue was facilitated. This helped them to better identify, and broach, different perspectives:

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> **James:** *…we'd make a point and then she'd, not necessarily ask a question but say something that would make you reconsider, which I quite enjoyed, kind of. 'Cause then something that I'd believed quite stubbornly, I'd be like, 'Oh, maybe not… maybe I should think a bit more.*

Engaging in philosophical dialogue can therefore prompt students to reflect and challenge entrenched patterns of thinking. The school experience also encouraged the undergraduates to exercise judgement because they reflected upon their own philosophy workshops when planning and facilitating the school sessions. At times, they were pleasantly surprised by the sophistication of the school pupils' arguments (see Respect, dignity and recognition below). However, at other times they were shocked when pupils uncritically deferred to, and expressed seemingly unbridled trust in, government authority:

> **Andrew** *…in the first school we visited, it was almost chilling in that some of the reasons they had. So we had, for example, 'This bottle will give you a perfect memory. Would you drink it or not?' And quite a few of them had their reasons, 'Well, is it government approved? Is it regulated?' And sort of, it wasn't: 'If it's illegal, we won't take it.' It's that: 'If it's legal, we'll take it because they know what they're talking about.'*

There may therefore be a need for an explicit space for critical thinking in secondary schools to enable pupils to reflect upon the quality of the criteria they use to inform their arguments. While it is unclear from the interviews whether the capabilities that the undergraduates developed resulted from the undergraduate workshops or school outreach, it is evident that *Talking Chemistry* as a whole helped them become better at thinking critically and expressing their perspectives in a tactful and respectful manner.

Developing capabilities: Educational resilience

Exercising educational resilience involves negotiating risk and persevering in the face of adversity. Instances whereby students discussed persisting despite feeling anxious during *Talking Chemistry* were coded here.

Some undergraduates found *Talking Chemistry* particularly challenging, especially when they were asked to reflect on their assumptions. Some undergraduates found philosophical dialogue disconcerting because it made them conscious of uncertainties that they had not previously been aware of. Some found this unsettling because they liked chemistry precisely because it usually involves working with predetermined definitions and dealing with (perceived) certainties.

In creating a space in which disagreement - expressed through philosophical dialogue - was valued, undergraduates had to find (and hone) approaches to tactfully disagreeing with one another, even though expressing disagreement can be uncomfortable for both the challenger and the challenged. Learning how to do this well can be beneficial in the sense that, as one student observed: 'having an open discussion generates a more open and honest learning environment.' Some of the students who usually found it difficult to contribute to group discussions found opportunities to do so because, as one put it, there were: 'points in the enquiry when we paused the discussion to analyse how it was going and the possibility of directing and encouraging new ideas from people who had spoken less' (see Social relations and social networks below).

Interviewees spoke of developing educational resilience through the school experience. Even when they experienced trepidation about putting their own ideas into action and working with pupils, they continued nonetheless:

> **Robert:** *I was a bit panicked by it, and I thought, 'Oh God, what have I done? What I have gotten myself in for?' But no, I think it was an opportunity that I managed to make something out of, rather than let it get me, like, 'Oh, I'll stop coming after one week.' So, yeah..I'm glad I did it… I've never really had to, like, be given, kind of like work from the ground up. I've always been told to just follow this list, and things, so, I was a bit nervous, but..I think 'cause it was a sort of low pressure setting, it wasn't towards an exam, it was easier to stick with.*

The low-risk context in which *Talking Chemistry* took place, and the individual and shared group responsibility, appear to be among the conditions that encouraged the students to persevere. Undergraduates reported that not being assessed on their practice was important in enabling them to gain confidence in challenging situations.

> **Adriana:** *For some reason I decided that I could introduce it, the project and what we were going to do. Because, basically… no one was wanting to, no one was eager to do it. So I thought, 'OK, I can do it.' So I was really nervous about that because, I guess, public speaking is not my favourite thing. But it went OK in the end and everyone listened, so I was like, 'Oh…'*

Several undergraduates expressed surprise at how well the school workshop was received:

> **Jonathan:** *I was also kind of surprised about how well that went, I was slightly worried that we weren't prepared enough for it…I was also worried that, 'cause obviously you're going down to high school kids, there's every possibility that they're just not gonna care, and they're not gonna want to get into any kind of discussion. And so, like, how ready they were to sort of open up and start talking about their thoughts.*

Talking Chemistry therefore presented opportunities for the participants to take informed risks, and to persevere despite experiencing a degree of discomfort. They consequently achieved things that they found difficult, and became more enthused and resilient. However, it is important to note that the same conditions that made it possible for some students to take risks, such as the informality of *Talking Chemistry*, can simultaneously make it possible for others to avoid the exact experiences that are a prerequisite to becoming more resilient.

Developing capabilities: Knowledge and imagination

Cultivating knowledge and imagination involves gaining disciplinary or professional knowledge, whether for pleasure or personal development. It also involves debating complex issues, such as ethical issues. Questionnaire responses suggest that *Talking Chemistry* did not develop students' knowledge of chemistry; but did indicate that there had been some shift in students' perceptions of their knowledge of philosophy and philosophy of chemistry-related knowledge. The other domain of knowledge that *Talking Chemistry* worked within was education. Instances whereby students discussed gaining teaching experience; becoming more confident in professional scenarios; and using *Talking Chemistry* to enhance their CV were therefore coded here.

Observations suggested that some undergraduates found engaging in philosophical dialogue unsettling because knowledge is problematized and therefore treated differently to how it might typically be treated in formal chemistry education. Philosophical dialogue encourages critical reflection on the assumptions underpinning chemical knowledge.

> **Charlotte:** *Well, it was nice 'cause, again, it's not just like, 'This is what a mole is.' It's, like, let's think about what applications of chemistry and also, like, the philosophy behind, like, you know, what is an atom, what is a building block sort of thing.*

For most of the interviewees (4 out of 6), gaining knowledge about, and experience of, teaching performed an important role in motivating them to participate in *Talking Chemistry*. They had hoped to gain a better understanding of whether they would like to become teachers. While they benefited from this, with 5 out of 6 considering the notion of becoming a teacher after participating in *Talking Chemistry*, the pedagogical approach differed dramatically to that which they had previously encountered during both secondary and higher education:

> **Jonathan:** *…if I was ever going to go into education, sort of, these activities and the way it's structured would definitely be something that I'd think about. It was really successful in getting the kids to start talking about things. Like I said, more so than I kind of thought it would be.*

Interviewees also spoke of gaining knowledge about how to manage people; facilitate discussion; and teach.

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> **Andrew**:*…doing the presentation in the schools, that's a really amazing, useful experience to have… being able to do presentations to a wide range of audiences, and be able to do that from an educational point of view, and a facilitation point of view, is something that not many people have. And it really helps you stand out when you're trying to apply for whatever it is you chose to do.*

While in this case an instrumental approach to participation - based on enhancing employability skills rather than learning for its own sake - is evident, others' involvement in *Talking Chemistry* prompted them to reflect on their values and to consider their future career in light of them:

> **Robert:** *I'll definitely think more about what I'd do later in life if, I think, career wise. Sort of, I think I'd definitely do better in a job that would, that involves interaction, and group work, maybe. Urm, 'cause I've always sort of liked that, but now I've realised I can do it in an unfamiliar setting. So I'd probably do it in a job, maybe. Urm, yeah. Maybe teaching, or, that's sort of on my radar now and never was.*

Undergraduates reflected not only on their own knowledge and imagination, but also on that of others. They suggested that they see the pupils' voices as important when engaging with chemistry, and cited philosophical dialogue a potential means of elucidating them:

> **Charlotte:** *You want them to be discussing and be thinking about chemistry, so they're not thinking about, 'Oh, how would somebody else have thought about this?' Instead, they're thinking themselves about chemistry.*

In summary, participants developed their knowledge and imagination capabilities, but not necessarily in linear or anticipated manners. The participatory, interactive and responsive approach to *Talking Chemistry*, and the undergraduates' experience of facilitating philosophical dialogue in a school classroom, in particular, helped them to enhance these capabilities. For some, it encouraged them to consider a teaching career (or a career involving interaction with others), while for others it boosted their confidence in professional contexts and permitted them to improve their prospects in the wider graduate labour market by contributing to their CV.

Developing capabilities: Learning disposition

Learning disposition involves learning-oriented curiosity and confidence. Instances whereby students spoke favourably of their experiences; feeling inspired to continue philosophising; and of the perceived need for something like *Talking Chemistry* to be part of their degree were coded here.

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Undergraduates described their motivations for participating in *Talking Chemistry*. These largely related to doing something different, but related, to their degree. They had expected to learn about, rather than do, philosophy of chemistry, but described the interactive nature of *Talking Chemistry* as a pleasant surprise. In particular, they enjoyed creating philosophical questions, as well as developing, defending and challenging arguments:

> **James:** *you come to chemistry at university and it's all, kind of like, 'This is right, that is wrong. Don't argue.' …it's different to what you'll do, 'cause you don't debate much in this kind of degree, not at our level anyway. We don't really do much on ethics, it's kind of brushed over in some lectures, but, it's nice to just have, it's almost like, ethics is the main theme to this kind of thing, rather than it just being a little side note. Or like, a final page in a lecture.*

This corresponds to responses to open questions on the post-workshop questionnaire whereby students reported a need for more space for questioning, the sharing of ideas and thinking about abstract ideas on their degrees. Interviewees discussed the lack of space for philosophy, particularly ethics, in the formal chemistry curriculum. Adriana said that following her experience of engaging in philosophical dialogue, she began considering ethical issues when learning about chemistry:

> **Adriana:**…*when we do organic chemistry and we study different molecules, then I start to think about the ethics of it, yeah, sometimes. In lectures, yeah. I do that silently.*

In providing time for students to reflect on, create and share arguments, there is necessarily less time for content to be taught, which presents a challenge when introducing philosophical dialogue into content-rich subjects such as chemistry.

Philosophical dialogue requires authentic engagement, and the quality of the dialogue is a function of how well it is facilitated, as well as how hard students are willing to think. For some, this differed from what they have been used to during secondary and higher education:

> **Robert:** *I think I'd have to emphasise that it was something that was very you driven, and something you would take part in for your own enjoyment.*

Undergraduates cultivated their learning disposition through *Talking Chemistry*. They took philosophical methods and ideas beyond the workshops and into schools, and also to their degrees where they made links between chemistry and philosophy. Arguably, the main feature of *Talking Chemistry* that enabled undergraduates to develop this capability is that it required them to make decisions about what they wanted to do, what they wanted to do it about, and how they wanted to do it.

Developing capabilities: Social relationships and social networks

Social relationships and social networks involve building mutual trust, making friends and constructively participating in group work. Instances whereby students discussed debating, discussing and collaborating with others, as well as when they spoke of prompting pupils to think more critically, were coded here.

Whether unanticipated or not, all of the students said that the social aspect/s of *Talking Chemistry* were welcome:

> **Jonathan:** *I suppose I didn't expect to get tons out of it socially, but it was like a really nice opportunity to talk to people in Chemistry who, 'cause obviously we're on such a massive course, you don't necessarily get a chance to talk to every single person.*

> **Robert:** *I was looking forward to meeting some people that I hadn't had much time to socialise with. That was definitely a part of what I enjoyed, 'cause they're all very nice, and we had some good discussions, so, that was definitely a big plus. I enjoyed that part.*

This suggests that *Talking Chemistry* created a social space - permitting students to interact - that participants perceived to be deficient on their degrees. The dialogic nature of *Talking Chemistry* enabled this to happen. Furthermore, what participants learnt from participating in and facilitating deliberation appeared frequently in the data. While some participants found expressing their ideas initially challenging, all became progressively more confident:

> **Robert**: *By the end, we knew that we could challenge what we said. And I think I would be less scared to do that now. You do sometimes need to challenge other people's thoughts, so, I think I'll definitely take that forward…. I think it just made you braver really, and that, 'This is what I think…' And then, 'Challenge me…'*

Undergraduates valued discussion time, and appreciated that they could steer the direction of discussion through the creation and selection of questions. However, some needed repeated practice of engaging in philosophical dialogue to kindle their confidence:

> **Adriana**:*…at first I was a bit more reserved. But then, once I saw everyone contributing, I thought, I guess I should do the same.*

Regarding the school workshops, participants described becoming better at facilitating discussion, which involved learning to give pupils space to talk:

> **Charlotte:** *…facilitating discussion is like a different skill than just, sort of, standing around and monitoring*

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students. Urm, on my [school] placement I was just, like, a teaching assistant I guess… it's interesting, being able to interact with kids on a more, like, personal level. And actually be able to talk to them properly, rather than just be like: 'Are you doing your work, buddy?'

Interview and questionnaire data suggest that social networks were made as a result of the discussion, and that an important feature of the discussion was that it was open, authentic, and required students to create philosophical questions of interest to them, and to take a position - which was open to change - and share their reasoning openly.

Developing capabilities: Respect, dignity and recognition

Respect, dignity and recognition involve showing empathy, compassion, fairness and generosity, listening to others and speaking out. Instances whereby students discussed being sensitive towards others; becoming exposed to alternative perspectives; or considering how to make classroom material appropriate for secondary school pupils were coded here.

Participants described encountering ideas they had not previously considered. Describing an enquiry on the development of medicines to treat post-traumatic stress disorder, Andrew said:

> **Andrew:** *…it's nice to have a discussion where people can be like, 'OK, well, I think this because…' And see the different things people place emphasis on, because you can see in a room. So we did one on memory and identity, and some people were placing emphasis on the fact that you'd be inherently changing yourself, and then they didn't really like the thought of messing with your head like that. And then some people were, sort of, 'Well, it's just like, 'cause you'd use it to get rid of traumatic events.' And that sort of like, healing, 'cause you're gonna alter your state anyway.*

Most (5 out of 6) participants described their pleasant surprise at how ready pupils were to share their ideas:

> **Jonathan:** *They were more surprising with how, like, some of them just came out with stuff in the way that you're just like, 'How the hell did you think of that?' I had no idea. That's not been mentioned by any of us.*

This suggests that, as well as being exposed to new ideas during *Talking Chemistry,* participants also became more respectful of pupils - and by extension, young people in general - through the school workshops. They were surprised at the depth, maturity and sophistication of the pupils' responses and emotional intelligence. Indeed, the undergraduates explicitly stated that they had underestimated the intellectual and social capabilities of young people, and that this was clearest when pupils shared perspectives that the undergraduates themselves had not considered during earlier deliberations:

> **Robert:** *I underestimated how good they'd be at the discussion.*

This demonstrates that the participants became more respectful of young people through *Talking Chemistry,* and that what made this possible was the experience of facilitating discussion among - rather than teaching content to - young people.

Developing capabilities: Emotional integrity

Emotional integrity involves coping constructively and productively with stress- or anxiety-inducing situations, which can otherwise act as impediments to learning.

While the activities involved in *Talking Chemistry* can be challenging, observations and questionnaire responses suggested that the undergraduates were not put off. Importantly, undergraduates carefully consider not only their own anxiety, but also that of school pupils:

> **Jonathan:** *…we had a lot of discussion about making sure that all the content we had for the class was going to be appropriate, making sure that it was, sort of, abstract enough that you weren't gonna make any of the kids feel uncomfortable.*

Similarly, James discussed this in the context of planning and facilitating the workshop, which focused on the use of performance enhancing drugs (which pupils may have experienced directly or indirectly):

> **James:** *We tried to avoid using proper, like, really clear examples so that the kids wouldn't go home and say, 'Mummy, what's heroin?' Or, if, obviously Ritalin is a kind of drug that you use to, like, attention focusing kind of drug. But it also a prescription. And we had no idea whether any of the kids might have been taking it. And we didn't just wanna say, 'Oh yeah, Ritalin, that's a smart drug, and can help you do work…' 'Cause then we'd be discussing the ethics about, that particular, that kids kind of choice. So we thought it's best to kind of steer away from named examples as much as possible.*

Robert discussed learning how to facilitate sensitively, noting the need to tactfully elicit responses:

> **Robert:** *I sort of feel like I've got a better manner of doing it, that presents it in a, like, non-confrontational way… sometimes people got visibly flustered or felt passionately about something, and you would know to step a step back and not be, like, forceful with your questions. Or, like, make them feel uncomfortable.*

This suggests that the freedom undergraduates had over the content and facilitation of their deliberations and the school

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session enabled them to enhance their emotional integrity through considering the impact of the content and their interactions.

Developing capabilities: Bodily integrity

Bodily integrity relates to freedom from physical and verbal harassment. Ground rules were established by the participants in advance of discussions, and that each dialogue featured reflection on the process and content of it. The nature of the content under discussion was at times contentious. For example, when discussions related to strongly-held positions on animal rights and veganism, memory and identity, and emotional trauma, students interacted in a tactful, sensitive and respectful manner (as discussed above) that meant others felt free from threat:

> **Andrew:** *I would describe [interactions with peers] as productive. And, enjoyable, in that we were able to have a good philosophical discussion, in all the ways that a philosophical discussion is good. You've got points being raised, good counterpoints. Nobody starts making personal attacks or anything like that.*

This capability relates to emotional integrity and respect, dignity and recognition, and was cultivated through reflecting on, and practising, sensitive ways of expressing thoughts. In other words, what made bodily integrity possible was the development of other capabilities, which related to interacting with one another, and pupils, in an appropriate manner.

Discussion and Conclusions

Philosophical dialogue fills an unmet need in undergraduate chemistry. While the case for philosophy in chemistry has been made in the research literature, we have not found any reports of how philosophical dialogue has been introduced to or received by undergraduate chemists. Here, we present a method by which philosophy can be introduced to undergraduates through its methods in an extracurricular space. Findings contribute to our understanding of the role philosophical dialogue can perform in chemistry education in HE. We have presented a practical approach to doing philosophy with undergraduates and demonstrated that, as well as how, it can contribute to their capabilities. While several authors have advocated for the place of philosophy in chemistry education (Scerri, 2000; Erduran 2001), this study puts these ideas into practice and provides a model for allowing students to learn how to engage in, facilitate, plan and reflect on philosophical dialogue. The methods used suggest possibilities for evaluating chemical education based on wellbeing rather than satisfaction. The findings from this study support calls for the inclusion of approaches from the humanities in science education (Nussbaum, 2010). Furthermore, the data we have collected support the idea that philosophical dialogue in chemistry opens up opportunities for the discomfort that is required for learning and, indeed, flourishing; philosophical dialogue through a community of inquiry created a safe space for the disagreement and discomfort necessary to allow learning to occur and for students to develop capabilities.

This study presents a novel approach to understanding educational impact, focusing on creating well-being through the development of capabilities rather than student satisfaction. Such an approach is under-used in educational research, despite the fact that it values the freedom that individuals have to achieve outcomes of value to them (Sen, 2009). In keeping with Dean & Gibbs (2015), participants in this study took an active approach to their engagement with philosophical dialogue, and although they experienced difficulty, discomfort and challenge, they were able to confront this. In doing so, they developed capabilities identified by Walker (2005); namely: practical reason, knowledge and imagination, disposition to learning, social relationships and emotional and bodily integrity. By asking questions and exploring ideas of their own choosing, we suggest that the alienation described by Na & Song (2014) and Erduran (2001) in the sense of chemistry being difficult and removed from students' lived experiences can be overcome, because students create and answer their own questions. However, this shift in responsibility can be challenging for students as they are placed outside their zone of comfort in terms of knowledge (becoming more aware of the limitations of their own subject knowledge, and of chemistry) and process (disagreeing and being disagreed with). While philosophical dialogue is not appropriate for teaching content, this study suggests a role for it in engaging students in discussions about how chemists create knowledge and for exploring ethical issues in chemistry. These are things that the participating students perceived to be important for chemists, but missing from their educational experience to date. Philosophical methods such as conceptual analysis can also act as a tool for self-reflection on students' understanding of key concepts in chemistry, and the process of question creation can help students to explore ideas about which they are curious.

The first research question that this study posed was: 'What are undergraduate students' experiences of philosophical dialogue in chemistry?' Participants gained knowledge of philosophy and its methods, and became more confident about the prospect of expressing their ideas. The majority of participants who participated in the workshops were positive about their experiences and saw a place for philosophical dialogue in chemistry education. Although the gains that students reported may not be priorities for university chemistry educators, concomitant effects in terms of learning disposition and knowledge and imagination are likely to be of benefit in chemistry learning situations.

The second question this study posed was: 'How, if at all, can experiencing and leading philosophical dialogue in chemistry outreach foster undergraduate students' capabilities?' Through questionnaire responses, observations and

interviews, we were able to understand the ways in which philosophical dialogue in chemistry fostered students' practical reason, knowledge and imagination, learning disposition, social networks, respect for others, and their emotional and bodily integrity. Students developed these capabilities through the creation of philosophical questions, their contributions to group discussion, interactions that allow respectful disagreement, through being questioned, and the supported responsibility they had for developing and delivering their own philosophical dialogue workshops in schools. Philosophical dialogue contributed to students' capabilities by providing a space for challenge, taking risks and dealing with uncertainty in chemistry.

The main limitations facing this study stem from the small sample size and voluntary participation. It is possible, for example, that the voices of those who do not like to question chemical authority or who are focused on more instrumental outcomes of HE are not represented in this study. An additional limitation is that in using Walker's ideal-theoretical capabilities framework, other capabilities of importance may have been neglected.

The future direction for this work is to integrate it into an optional final year Chemical Communication module, where some of the approaches have been piloted previously. The approach could also contribute to Chemical Ethics or Chemical Education modules, or Foundations of Chemistry modules in the later stages of undergraduate programmes. Some strategies used could readily be incorporated into lecture, seminar or workshop situations.

Conflicts of interest

There are no conflicts of interest to declare.

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Table 1: Overview of Taking Chemistry

	Focus	Format	Facilitated by	Content
Part one: learning about philosophical dialogue in chemistry	Discussion	Workshop	Staff	**Learning to do** philosophical dialogue about chemistry through application of philosophical methods (questioning, conceptual analysis and thought experiments) to chemistry.
	Facilitation	Workshop	Staff	**Learning to facilitate** philosophical dialogue through questioning and peer discussions, and reflection on the inquiries experienced by students.
Part two: outreach in philosophical dialogue in chemistry	Planning	Meetings	Students and staff	**Learning to plan** philosophical workshops for school pupils, link ideas to the school curriculum and anticipate potential difficulties. The themes selected were 'Better Brains and Better Bodies through Chemistry' (human enhancement), 'Alien Investigators from Twin Earth' (material and human interactions) and 'One Planet Philosophy Loft' (chemistry and sustainability).
	Application	Outreach workshop	Students	**Learning to apply** planning and facilitation skills, and to reflect on educational experiences. Three state comprehensive schools hosted sessions for key stage 3 ~~students~~ pupils (age 11-14) and undergraduates planned philosophy in chemistry events for their student community.
	Evaluation	Meetings	Students and staff	**Learning to reflect** on practice. Post-outreach reflection meetings over refreshments were held to discuss and reflect on the students' school experiences drawing on comments from pupils, teachers, themselves and staff.

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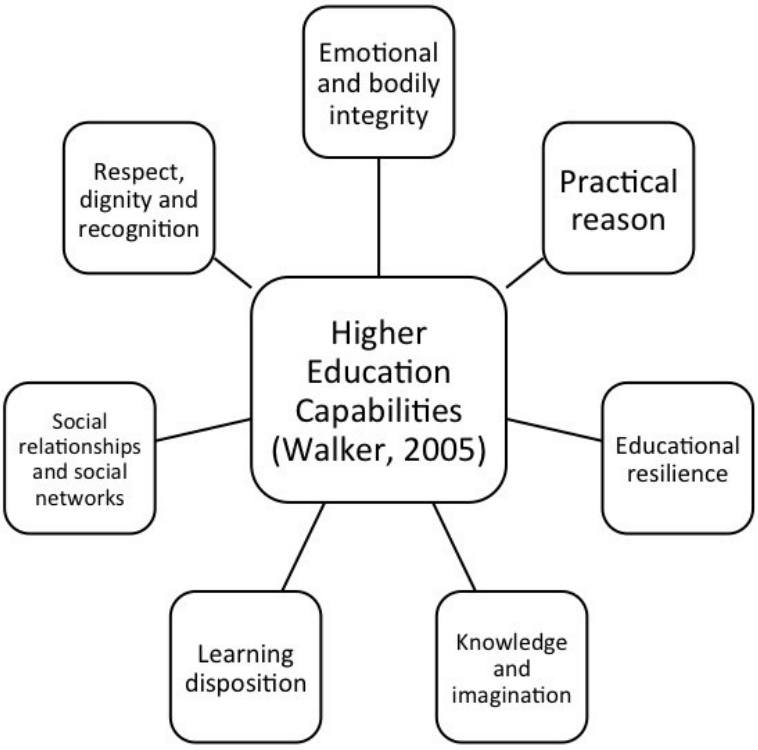

Figure 1: Capabilities for Higher Education (Walker, 2005)

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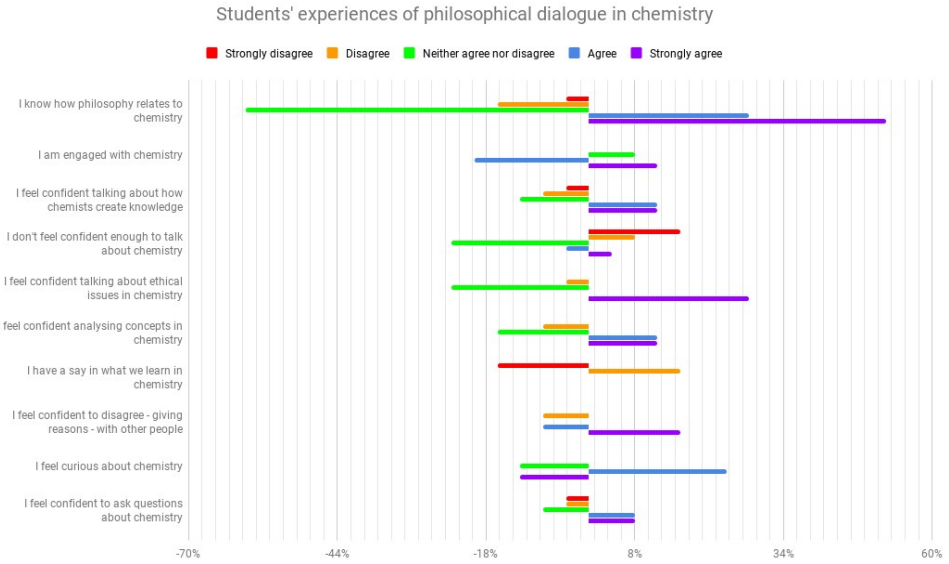

Figure 2: Students' experiences of philosophical dialogue in chemistry

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Table 2: Building capabilities through *Talking Chemistry*

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Capability	Characteristic of Talking Chemistry
Practical reason	Undergraduate students were invited to make decisions (e.g. about their position in response to a question) and to share their reasons orally or physically (by moving in space to reflect their thinking). Possibilities for exercising judgment in educational situations were created by asking those who participated in school-based sessions to prepare and deliver philosophy in chemistry workshop aimed at pupils aged 11-14.
Educational resilience	Presenting opportunities for negotiating risk and persevering through philosophical dialogue. Presenting the challenge of putting ideas into practice in schools, and adapting to the constraints of schools. Working with difficult ideas and uncertainties at the philosophy/chemistry interface.
Knowledge and imagination	Enabling students to use (and understand) the methods that are used in philosophy to gain knowledge of chemistry. Prompting students to create philosophical questions about chemistry. Providing opportunities to discuss complex and/or controversial epistemological and ethical issues in chemistry.
Learning disposition	Students asked to create their own philosophical questions for group discussion; group commitment to discuss philosophical questions of others requires curiosity and confidence in ability to learn.
Social relations and social networks	Workshops required group participation - in large and small working groups to create questions, explore responses, analyse ideas and to collaborate on planning lessons suitable for young people in schools. Students had sole responsibility for leading the school workshops.
Respect, dignity and recognition	Workshops involved listening to and considering other points of view in dialogue. Co-created ground rules described how to respect ideas (through disagreement and counterargument) and people (through active listening, empathy, generosity and speaking out)
Emotional integrity, emotions	Care was taken to avoid anxiety or fear by encouraging (but not requiring) all students to speak in groups of different sizes; different types of contribution requested (single word to developed counterargument). Silent discussion (where no talking is permitted; students must write answers and respond to each other on a large sheet of paper) as well as oral discussion used.
Bodily integrity	Creating shared ground rules for discussion and handling disagreement; how to handle disagreement whilst maintaining safety and freedom from verbal harassment; open horseshoe seating without desks.

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Item	Text
1.	I know how philosophy relates to chemistry.
2.	I am engaged with chemistry.
3.	I feel confident to talk about how chemists create knowledge.
4.	I don't feel confident enough to talk about chemistry
5.	I feel confident to talk about ethical issues in chemistry
6.	I feel confident to analyse concepts in chemistry.
7.	I have a say in what we learn in chemistry.
8.	I feel confident to disagree – giving reasons - with other people.
9.	I feel curious about chemistry.
10.	I feel confident to ask questions about chemistry

Table 3: Pre- and post-workshop survey items

Responses allowed: strongly agree; agree, neither agree nor disagree; disagree and strongly disagree.

Ormat		SD	D	N	A	SA
1	I know how philosophy relates to chemistry.	-4%	-16%	-60%	+28%	+52%
2	I am engaged with chemistry.	0	0	+8%	-20%	12%
3	I feel confident to talk about how chemists create knowledge.	-4%	-8%	-12%	+12%	+12%
4	I don't feel confident enough to talk about chemistry	+16%	+8%	-24%	-4%	+4%
5	I feel confident to talk about ethical issues in chemistry	0%	-4%	-24%	0%	+28%
6	I feel confident to analyse concepts in chemistry.	0%	-8%	-16%	+12%	+12%
7	I have a say in what we learn in chemistry.	-16%	+16%	0%	0%	0%
8	I feel confident to disagree – giving reasons - with other people.	0%	-8%	0%	-8%	+16%
9	I feel curious about chemistry.	0%	0%	-12%	+24%	-12%
10	I feel confident to ask questions about chemistry	-4%	-4%	-8%	+8%	+8%

Table 4. Pre- and post-project changes in self-reported confidence in chemistry and philosophy

Notes: *n* = 25. Percentage changes in response to statements after *Talking Chemistry* had taken place. SA=strongly agree, A = agree, N=neither agree nor disagree, D = disagree, SD=strongly disagree.

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Learning about philosophy and chemistry: responses from students	**What practices helped you learn: responses from students**
• More the relationship between chemistry and philosophy (e.g. memory and medicines) • How chemistry is interlinked with so many disciplines and how to make that connection. • How philosophy can be applicable to science – never thought before about how it could. • How to critically analyse philosophical questions (what is and what isn't chemistry). • To define terms. • There are so many points of views for certain topics • How we can challenge concepts in chemistry. • That often philosophy provokes more questions. • The importance of 'why' and 'should'. • How to structure a philosophical conversation. • The ethics behind discovery. • What considerations we need to make about what we are doing in scientific research and how it can be used.	• Big discussion about memory, happiness and liquids. • Sorting philosophical and non-philosophical questions. • Discussion about quotes about chemistry. • Silent discussion. • Lollypop discussion comparing two words (especially with ones with proton/hydrogen ion and particle/electron). • By questioning things that were presented as fact. • Hearing other people's ideas. • 'Unfair questions. • Thought experiments. • Discussion perceptions of facts. • Comparison of analysis in philosophy and chemistry.
Learning about pedagogy: responses from students	**What practices helped you learn: responses from students**
• How to stimulate discussion in different ways • To be prepared for unanswerable questions. • How to comment on the ideas of others. • Different activities probe the same question can be used to involve those who don't feel confident to speak out loud and give them a voice. • Different ways to engage students. • How to encourage discussion in an efficient manner; how to have ore fruitful discussion • How to create a session that's interactive, engaging and interesting. • Ways to build on other people's ideas.	• Activities to use in class modeled • Lollipop discussion. • Silent discussion. • Whole group discussion. • Open discussion – it generates a more open and honest learning environment. • Reflection on how our sessions could be adapted for a class. • Facilitation.
Miscellaneous comments	
• Make it a college workshop. • Have more sessions like this. • Have this more frequently or build it into the course. • Make it part of the normal curriculum. • Try to do this in the department. This would be beneficial for all chemistry degree students. • This should be run with students in all years. Very useful. • How much joy I gained from peer to peer discussion – a useful way to bring philosophy in science to any audience. • Refreshing. • Inspirational. • A great chance to engage in philosophical discussion which many people have far few opportunities to do. • Helps with different ways of thinking. I felt it benefitted me greatly. • Thought provoking. • We need this to be compulsory – I've used my brain in a totally different way – was nice to be able to answer and ask questions and know no-one would think I was being stupid. • The idea of ethics in science should be discussed more in course. People should be encouraged to hear different ideas and feel safe to share them.	

Table 5: Post-workshop open responses

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Appendix 1: Teaching material

Drawing distinctions

The following pairs are written on lolly sticks and given out, one lolly stick per pair. Students are asked: 'can you state the way(s) in which the following pairs are the same, and the way(s) in which they are different?'

1. Tunnel / Cave
2. Molecule / Compound
3. Reason / Excuse
4. Smart / Intelligent
5. Teaching / Training
6. Medicine / Drug
7. Debate / Discussion
8. Mind / Brain
9. Theory / Hypothesis
10. Risk / Danger
11. Analysis / Argument
12. Memory / Identity
13. Cure / Enhance
14. Repair / Improve
15. Memory / Identity

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Appendix 2: Teaching material

Identifying philosophical questions

If a philosophical question is a question to which answers are in principle open to informed, rational, and honest disagreement and which require reasoning to be answered, which of the following are philosophical questions? Why?

- Who discovered oxygen?
- Are atoms fundamental particles?
- How many grams are in a kilogram?
- What is an electron?
- Can a carbon dioxide molecule be bad?
- How did life on Earth begin?
- Is it possible to know how life on Earth began?
- What would a Hippocratic Oath for chemists contain?
- If you take a drug to make you happy, are you happy?
- What is the evidence for anthropogenic climate change?
- How many types of bond exist?
- Can theories about the origin of life on Earth be tested?
- Is there hydrogen in the sun?

Philosophy Loft exchange your views on a philosophical question in exchange for a drink.

- Does it matter if Earth becomes inhospitable to humans?
- What is wild about England? About York?
- Should people colonise other planets?
- Is it important to have global sustainable development goals?
- What are the most convincing arguments for veganism?
- Should financial incentives or punishments be used to promote pro-environmental behaviour?
- Are positive imaginings of the future necessary?
- Is pollution unethical?
- Who benefits from current environmental policies?
- Is clean air natural?
- If climate change does not affect you, to what extent is it real?
- What is an inconvenient environmental truth?
- Should people be exposed to the methods of production of consumer goods?
- What responsibility do you have for the pollution you create?

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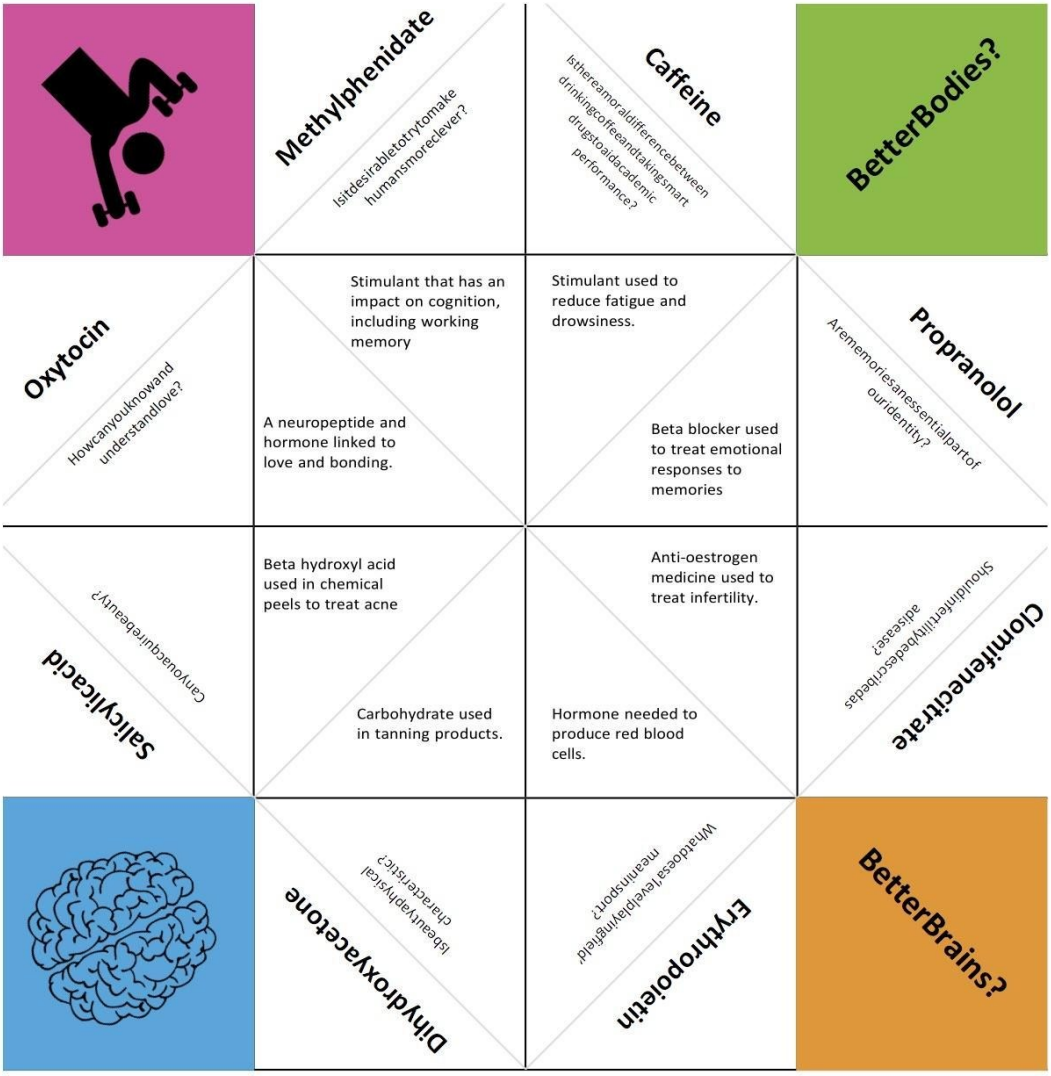
Appendix 3: Student created resource for doing philosophy in chemistry

Discussing philosophical questions

Provide a copy of this 'finger volcano' to a group of 4 to fold and play.



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Appendix 4: Teaching activity for chemical enhancement

Better Brains Better Bodies

Read the examples and decide whether or not these uses of chemicals in human bodies are permissible or not. Make a note of the criteria you are using to decide. You will be asked to feedback your criteria, not your answers.

A footballer takes steroids to help them recover from exercise and build more muscle.	*A model uses a chemical peel to remove dead skin cells and stimulate the growth of new cells.*	*A boxer uses a synthetic form of a hormone to increase muscle mass and motivation to compete.*
A cyclist uses artificial EPO (a drug made by the body) to make red blood cells to help them cycle longer.	*A celebrity on a TV programme uses spray tan to give them a bronze glow under the studio lights*	*A woman uses a synthetic form of a naturally occurring hormone to treat infertility.*
A teenager has a dental implant to replace a front tooth lost in an accident.	*A darts player takes beta blockers to help them keep a steady hand and eye.*	*An athlete uses a salbutamol inhaler to relieve the symptoms of asthma.*
A rugby player uses a strong painkiller to endure tougher training sessions.	*A male adult uses a strong painkiller to relieve toothache.*	*.A chess player takes beta blockers to treat a heart problem.*

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Appendix 5: One Planet Week Philosophy Loft

Sample stimuli for philosophical discussion at the One Planet Philosophy Loft

Bar area: exchange of ideas not money

Select a question and discuss with the bartender in exchange for a drink. Example questions:

- How do we know that what scientists say about climate change is true?
- Is there a difference between H_2O and water?
- Is nature inherently beautiful?
- How does the environment we live in shape our understanding of reality?
- Is it possible to own air?
- Is nature a resource that should be used to conduct experiments?
- Should all life on Earth be protected?
- What is sustainable living?

Fair trade and consumer choice

Offer a choice of products (chocolate, wine). If the non fair-trade option is selected, ask if the participant would like to change their mind and take the fair trade product instead. Ask reasons why/why not, and what the consequences of this are.

One Planet and Rawls' Veil of Ignorance

- Imagine you are deciding on laws to protect the environment.
- Discuss, then decide on the most just laws from behind a veil of ignorance (i.e. not knowing what position you will have in the world you create).
- Once you have agreed on your laws, open an envelope (each envelope contains a brief description of a role, e.g. a global CEO of a plastic manufacturer, newborn child, inhabitant of a low-lying island nation, pilot, dairy farmer) to reveal your position in your world.
- Discuss how the new 'you' would respond to your laws.
- Reflect: did you create just laws?

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Appendix 6: Interview guide

Talking Chemistry: Non-formal education in Chemistry, Education and Philosophy

Expectations, motivation, choice

- What did you expect when you heard about Talking Chemistry? Why?
- What made you decide to take part in Talking Chemistry?
  - Why did this interest you?
  - Why was this important to you?
- Were there any other motivating factors that helped you to decide to take part?
- What, if anything, did you hope to get out of Talking Chemistry personally? Why was this important to you?
- What, if anything, did you hope to get out of Talking Chemistry academically? Why was this important to you?
- What, if anything, did you hope to get out of Talking Chemistry socially? Why was this important to you?

Outcomes and values

- How was Talking Chemistry different to other approaches to education in chemistry/education/philosophy you have had to date?
- What did you gain from being involved in Talking Chemistry?
  - How does this relate to what you expected?
- Was there anything surprising about the project and the approach?
  - Was this important to you?
- What, if anything, did you learn about philosophy (particularly ethics)?
  - What was it that enabled you to learn this?
  - To what extent was this important to you?
- What if anything, did you learn about education?
  - What was it that enabled you to learn this?
  - To what extent was this important to you?
- What if anything, did you learn about chemistry?
  - What was it that enabled you to learn this?
  - Was this important to you? Why?

Capabilities: freedom to do and be

- What were the most significant experiences for you? (Consider workshops, planning meetings, peer and staff interactions and experience in schools)
- Are there things that you have gotten out of participation in the project that you will continue to use or work with?
- What are you interested in doing in the longer term?
- What do you need in order to achieve this?
- Are there any opportunities or experiences you have had through the project that you think will help you achieve this?
- Did anything surprise you about the project or your participation in the project?
- Did anything challenge you?
  - Working across disciplines?
  - Working across phases (school/higher education)
  - Interactions with peers?
  - Interactions with staff?

Concluding questions

- On the basis of doing the project, how would you now describe it to others?
- What would you say were the key outcomes of the project for you?
- Is there anything else it is important for us to know about Talking Chemistry?

Thank you for taking part