International Journal of Science Education, Part B

Communication and Public Engagement

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rsed20

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To cite this article: Clare Wilkinson & Amanda D. Webber (2024) ‘It’s kind of placed a real challenge in my head’: threshold concepts and science communication education, International Journal of Science Education, Part B, 14:4, 436-449, DOI: 10.1080/21548455.2024.2412258

To link to this article: https://doi.org/10.1080/21548455.2024.2412258

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, PART B
2024, VOL. 14, NO. 4, 436–449
https://doi.org/10.1080/21548455.2024.2412258

Routledge
Taylor & Francis Group

SPECIAL ISSUE: ACHIEVING COMPETENCE IN SCIENCE COMMUNICATION: FURTHER EXPLORATIONS

'It's kind of placed a real challenge in my head': threshold concepts and science communication education

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ABSTRACT

'Threshold concepts' have recently been identified as a key component for higher or university level teaching in science communication, concepts which can offer a 'transformative' experience amongst students, whilst also creating a sense of discomfort. In this research article, we examine data gathered via two qualitative focus groups and a thematic analysis of 14 reflective learning journals conducted during a M.Sc. Science Communication based in the United Kingdom. Analysis of this data showed that all four threshold concepts (deficit model vs public engagement, audience-centred communication, co-production of science and society, and trust) and two learning concepts (learning progressions and community of practice) were represented in this sample. An additional topic area raised by students was around inclusivity and accessibility, which opens a discussion as to whether this should be considered a concept in itself or recognised as integrated into the other threshold concepts. This study supports previous work in identifying key threshold concepts for science communication and education, and how they can be researched. It also suggests that whilst learners share and articulate core experiences around these concepts, they are potentially most useful for those involved in teaching and curriculum design.

ARTICLE HISTORY
Received 29 February 2024
Accepted 29 September 2024

KEYWORDS
science communication; public engagement; higher education; threshold concepts

Introduction

Lewenstein and Baram-Tsabari (2022) recently called for the need to organise science communication trainings to achieve competencies. Their article highlighted 'threshold concepts' as a key area for higher or university level teaching in science communication; 'a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress' (Meyer & Land, 2003, p. 1). Unlike a core concept, threshold concepts are likely to be transformative and science communication can include recognising audience-centred communication, understanding of the deficit model vs public engagement, and having an awareness of both the role of co-production in science and society, and trust (Lewenstein & Baram-Tsarabi, 2022). Their transformative nature means they can be uncomfortable and 'troublesome' for some students, but a necessary transition to support progress in learning within the science communication discipline.

Whilst some attention has been given to engagement as a threshold concept in science communication (McKinnon & Vos, 2015), amongst other competencies (Fähnrich et al., 2021),

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Lewenstein and Baram-Tsarabi (2022) have identified the need for empirical studies to explore these concepts further, to clarify what threshold concepts exist in science communication and how they can be organised. This research article draws on more than 15 years of experience with postgraduate students to answer that call.

Taking an audience-centred approach, public engagement, trust and co-production of science and society underpin the teaching in the Science and Society module of the M.Sc. Science Communication based at the University of the West of England (UWE Bristol), U.K. Wilkinson leads the Science and Society module and Webber leads the programme as a whole. As the first module of the programme, uncomfortable, transformative learning is anticipated as part of Science and Society, and students are supported through the experience with an assessment that comprises a reflective learning journal. They are given the opportunity to identify and discuss reactions to these types of concepts, as well as other examples, through an appraisal of the literature, taught content, and their experiences. Anecdotally, we have observed that in the course of this assessment, students frequently refer to 'threshold concepts' albeit not using that terminology; however, we have not conducted any analysis of this body of work to date. We set out to design a small-scale research project, which could be conducted within one year, focusing on the following research questions:

(1) What threshold concepts are apparent in reflective learning journals completed by M.Sc. Science Communication students at UWE Bristol?
(2) How do these threshold concepts relate to those presented in Lewenstein and Baram-Tsabari (2022)?
(3) Are there additional threshold concepts present?
(4) How do students perceive the role of threshold concepts in their science communication education and training?

Threshold concepts

Threshold concepts have been referred to in educational settings for over two decades and were first developed in the context of U.K. higher education, where they were used in relation to research on undergraduate teaching (Cousin, 2006). Threshold concepts are conceptually rich, and understanding such concepts is seen as key to proceeding further in one's learning, allowing for transformational shifts, and greater depth and sophistication to be introduced (Lewenstein & Baram-Tsarabi, 2022). However, they can also have a more practical emphasis, as they encourage educators to focus on the core fundamentals for a subject they are teaching, and 'streamline' content, rather than to simply pack the curriculum with more and more topics (Barradell, 2013; Cousin, 2006).

Threshold concepts can become 'assimilated' by a learner, becoming part of who we are and how we feel (Cousin, 2006, p. 4), even though initially they may counter our intuitive understandings of a situation. Threshold concepts can expose connections that were previously unseen and can be irreversible in nature, whilst at the same time encouraging the learner to continue to research, question and critique their explanatory power (Cousin, 2006).

Despite their widespread uptake in educational fields, identification of threshold concepts has been challenging (Barradell, 2013). Furthermore, there is not currently one agreed methodological approach, and interviews, observations, grading and assessment feedback have all been used to assess their importance, and studies have been carried out with multiple purposes, including to influence curriculum design, understand pedagogical approaches and to improve teaching quality (Quinlan et al., 2013). Nonetheless, Timmermans and Meyer (2017) identify several ways in which threshold concepts can be identified, including on the basis of previous research, in consultation with fellow teachers (akin to the approach taken by Lewenstein & Baram-Tsarabi, 2022), through consultation with students, and in consultation with professionals and community members in the relevant field.

Science communication and threshold concepts

Lewenstein and Baram-Tsabari (2022) identify four initial threshold concepts for science communication training (p. 2–3), which we summarise here:

- *Audience -centred communication*. Starting from the proposition that an audience should be identified, understood and active and that communication should start from an understanding of their needs.
- *Deficit model vs. public engagement*. An acceptance of the insufficiencies of the deficit model to understand the value and societal role of public engagement approaches.
- *Co-production of science and society, making values a fundamental part of science*. Recognising that values exist in science and amongst scientists, science communicators can reflect on their relationships with science, scientists, and audiences, including the importance of trust.
- *Trust*. Science is reliant on trust both among scientists and with broader audiences. Competency, integrity, benevolence and transparency about the values of researchers and audiences are critical.

Although we are primarily focused on threshold concepts in this article, Lewenstein and Baram-Tsabari (2022) identify two further learning concepts, which are important in assisting students to transition in their science communication education, these are *learning progressions* and *communities of practice*. Learning progressions offer a framework or pathway for knowledge that helps learners to develop their reasoning, development and expertise, and where learners return to specific topics (concepts and skills) building the depth and nuances of their knowledge (Lewenstein & Baram-Tsarabi, 2022). Communities of practice help students to develop their identities as a science communicator, building on Lave and Wenger's (1991) theories where one moves from periphery participation in a community to a more central role and building on previous studies that have also suggested threshold concepts can be a way to support the development of a professional identity (Nicola-Richmond et al., 2018). As Lewenstein and Baram-Tsabari (2022) highlight, what that role looks like and whether it is a goal of a programme may not be clear cut in science communication, since people can be 'occasional' science communicators, 'active' science communicators, or 'professional' science communicators and people can also move around these roles. Thus, in science communication contexts, a degree of flexibility is required.

Beyond the threshold concepts directly identified within the article, Lewenstein and Baram-Tsabari (2022) identify a series of science communication essential and advanced general learning goals, which can be applied in different ways for occasional communicators or active and professional science communicators, since they may have more advanced needs in their roles. These learning goals are grouped around 'affective', 'content knowledge', 'methods', 'reflection', 'participation' and 'identity' and since we are primarily focused on threshold concepts here, we focus particularly on learning outcomes associated to content knowledge. However, in doing so, we recognise that aspects featuring in other strands, such as affective strands that prompt communicators to value qualities like trust, would overlap with conceptual understanding.

Pedagogical approach at UWE Bristol

UWE Bristol is the largest provider of Higher Education in the South West of England; with over 38,000 students across three Colleges. Our student body is diverse; 20% of our students are from a Black, Asian and Minority Ethnic background and we have learners and staff from 163 countries. One fifth of our learners are mature students and 23% are disabled (UWE Bristol, 2023). We are a post-92 Alliance Group University (e.g. a former polytechnic) providing outstanding student experience (TEF, 2023) over 600 programmes of study: foundation and undergraduate degrees, degree apprenticeships, postgraduate taught and research programmes. We attain consistently

high assessment scores for teaching quality and student satisfaction. In September 2023, we were awarded a Silver overall rating in the Teaching Excellence Framework, which assesses higher education providers teaching and learning quality, with a gold classification for student experience. We have highly employable graduates – 91% of our graduates are in work or further study 15 months after graduation (HESA, 2023), we are 22nd in the United Kingdom for postgraduate student satisfaction (Advance HE, 2022).

The M.Sc. Science Communication is based in the School of Applied Sciences and is the flagship teaching programme for the Science Communication Unit, a research centre at UWE Bristol, established in the late 1990s. Since the M.Sc. started in 2003/4, over 300 students have graduated from the programme and it has received a 90%> satisfaction score in the U.K. Postgraduate Taught Experience Survey for the last six years (Advance HE, 2022). The most recent work we have conducted on our graduate destinations found that 77% now work in science communication, with a further 19% working in related fields, such as science teaching, for the National Health Service, as civil servants or in the (non-science) charity sector (Science Communication Unit, 2023). Since leaving the programme, 41% of our graduates have progressed to working in senior, strategic or managerial roles within science communication including as CEO's, and Directors of Communication, Engagement and Impact.

Applicants are encouraged from a diversity of disciplinary perspectives (Trench, 2023; Wood, 2023). A science undergraduate degree is not required for the programme and we welcome international students, with the rich, interesting and important social and cultural insights that they can bring to a predominantly U.K.-based programme, recognising that science communication is increasingly global in scope (Roche et al., 2023). With this in mind, when students join the programme they have navigated many different routes to discover an interest in science communication. Some will have undertaken a science communication module as part of a previous degree programme. Others will have been inspired by a media role model or an educator who enjoys communicating that they have met along the way. It is not unusual for us to welcome students (25% of our students' study with us part-time) who have been working in the field for some time, often without previous communications training, or, training in the fields in which they are now working in communication roles. We have developed a combination of modules that not only cover key theoretical and practical contexts for science communication and public engagement, but which do so with varied career routes and 'homes' in mind.

The Science and Society module is a compulsory module on the M.Sc. and the first module that students engage with (September–January). On successful completion of this module students achieve the following learning outcomes:

- Analyse the historical development and social contexts of public attitudes to science and technology.
- Analyse the problematic relationship between science and society.
- Explore the boundaries between the disciplines that contribute to the communication of science.
- Critically assess the potential of a variety of science communication activities to contribute to informal learning about science,
- Develop a reflexive approach to the practice of science communication,

These outcomes are achieved via a combination of lecture content, seminars and workshops, as well as academic specialists that join the module from organisations like the British Science Association and Royal Society. Students at the time of writing undertake three assessments as part of the module, one of which is a 1000-word reflective learning journal that is worth 15% of their marks for the module overall. The reflective learning journal can focus on a minimum of one and up to a maximum of three 'learning entries' and learning entries can include reflection on specific lectures/workshops, reading/s, professional practice and the development of academic skills.

Materials and methods

In May 2023, we designed a small-scale research project, which could be conducted within one year. The project utilised two methods; a textual analysis of reflective learning journals submitted in January 2023 and January 2024 to identify threshold concepts and learnings from their entries and focus groups (online via Teams) to discuss threshold concepts and their role in the programme following completion of student assessments. We contacted all 13 students who had previously completed the module in February 2023, and all 21 new students who started the module in September 2023 inviting them to participate in the research. We were conscious of the ethical dimensions of the research, since all students have a relationship with us as we have taught them. We went through the university ethics approval process and were mindful of the power dynamic in operation, carefully including a statement explaining that students could decline to participate in the data collection and that this would not in any way impact on their module or programme experience. Students received a participant information sheet, consent form (including the option to be acknowledged in this article) and the option to withdraw their data if they changed their minds.

Of the students invited to participate, 14 students (six from the September 2022 cohort and eight from September 2023) consented to their reflective learning journal being analysed, approximately 40% of students across the two cohorts. Regarding the focus groups, four students from each respective year 2022–2023 and 2023–2024, participated in two focus groups. The first focus group comprised only students from the September 2022 cohort. The second focus group involved students from both cohorts.

Our focus group questions probed whether students had heard of threshold concepts before and what they might understand or guess them to be. We asked if there were concepts from their studies they would define in this way and then introduced the concepts highlighted in the original article to students. Next, we discussed how the concepts related to any they would identify, whether there were gaps or key aspects that they thought were missing and if they covered the breadth of their MSc. We asked if any concepts had linked to or contradicted their experiences, whether the idea of learning pathways resonated with their experiences and if so, how, as well as any examples of teaching approaches that had supported their understanding of concepts. Finally, our questions included ways they could imagine threshold concepts would be useful to them as a learner or for their future work as a science communicator and how being a part of a cohort of learners was helping them to build an identity as a science communicator.

We undertook a thematic analysis of the 14 reflective learning journals and two focus group transcripts. Partly due to time limitations we made the decision to conduct a thematic analysis of the data, focusing on the four thresholds concepts identified in the original article, as well as the two learning concepts, *learning progressions* and *communities of practice*, rather than identifying codes using a grounded theory approach. We did however create a further code for *other* where we coded materials which did not link to these concepts but appeared to relate to something theoretically or empirically important conceptually. Wilkinson coded the reflective learning journals and Webber coded the focus group transcripts, we then reviewed all coding together for consistency, discussing each coded extract in relation to the relevant code or codes, before finalising the coding.

There are two final important points to note in regard to the methods. Firstly, the students who engaged in the focus groups from the earlier cohort of students had more time to consider and reflect on the impacts of their studies, since they were engaging in the focus group activities at least nine months after completion of the module, though there was no difference in the timing of their completion of the reflective learning journal. Secondly, for the September 2023 cohort, it was possible that an awareness of the research may have influenced their submission of reflective learning journals that are deemed to relate to the research, since we provided information on the research project to them at an earlier stage of their academic studies. Therefore, we included some clear guidance to students in advance, asking them to complete the reflective learning journal assessment as they would do if they were not aware this research was being undertaken, but it is a

possible limitation that some students may have focused more on threshold concepts with an awareness that this research was being conducted.

Results

We now discuss the four threshold concepts in turn, followed by the two learning concepts, as well as the content we identified in relation to *other* concepts we identified. The threshold concept most prominent in our data was *Deficit model vs. public engagement,* which featured in 15 of the 16 data files and to which 37 extracts of text were coded, followed by *audience-centred communication*, a concept identified in 12 data files and for which 35 extracts of text were coded. *Co-production of science and society* was evident in 10 data files, and 24 data extracts, whilst *trust* was present in 6 data files and 15 extracts of text. Data extracts are indicated by pseudonym, Full-Time (FT) or Part-Time (PT) student, Reflective Learning Journal (RLJ) or Focus Group (FG) and year. Where students have referred to authors, books and articles to these have been removed and are indicated by [reference].

Audience-centred communication

This threshold concept featured heavily in our focus group discussions as well as the reflective learning journals. This included recognition that there are different publics, audiences, and participants and that this underpins all elements of communication around science; students said that there is no one 'formula' and there is a need to tailor information to different publics. In reflective learning journals, students talked of the need to centre communications on audiences, developing a greater appreciation of the range of ways to engage different groups, and expressing concerns that if they made mistakes, they would need to reconnect with their participants, suggesting an increased valuing of those they sought to communicate with. Whilst breaking down audiences was important, there was also frequently a sense of wishing to share, listen and understand connections, as Heidi discussed in their reflective learning journal in relation to attending a science centre with a peer:

> One friend did make it clear, 'I won't understand any of it, but you can translate the hardcore sciency stuff'. This comment intrigued me and reminded me of the 'them vs us' narrative which has been perpetuated between scientists and the public until relatively recently; something I had been learning about in lectures. Heidi, FT, RLJ 2023.

Students discussed a sense of this new appreciation of audiences being a 'revelation' to them or something they had not really considered before. For example, when asked about concepts that resonated, Elsbeth responded:

> I think for me, it's probably the concepts of publics, about thinking of the public as so many different groups, because I think before I did maybe have that kind of view of thinking about communicating science to one public which is incorrect. And I think once I understood that concept, I was thinking more about how we need to like tailor information to different groups … To target different audiences means really listening to them and thinking about how the messages may be interpreted. Elsbeth, FT, FG2, 2024.

Whilst some students referred to past consideration of audiences, particularly if they were already working in the field, studying the programme had taken this a step further; they were now critically examining how to listen and engage people, and/or breaking audiences down beyond homogenous groupings, though this prompted questions:

> I suppose it's kind of placed a real challenge in my head because if you are potentially a white male middle aged scientist, how do you fully understand how best to communicate to somebody like an indigenous population or something like that? How can you? You can be told you need to consider your audience, but you don't have that lived experience. Tim, PT, FG2, 2024.

> This paper, among other reading, made me think about the importance of context in communication, and the notion that there is no single characterisation of 'the lay public'. It seems to me that science and society are

> both very human, and therefore very complex and 'messy' constructs that interact in 'messy' ways. Chanda, FT, RLJ, 2023.

We identify reflection taking place on challenges around the concept of audiences, for example regarding diversity (what about missing groups? where are the 'adult' audiences? What about those who are less well informed?) and questions also raised about how to safeguard the quality and value of communication, avoiding the treatment of audiences only as 'consumers', keeping in mind how participants benefit, and ensuring the quality of science communication remains high, regardless of the tailoring of content. We detect then much evidence that students are considering how to engage audiences, understand them and have them play an active role focused on their needs, but we also see the complexities of this in practical contexts being considered and expressed.

Deficit model vs. public engagement

As the most prominent threshold concept identified in our data, we noted many instances of students discussing or reflecting on the limitations of the deficit model and the value and societal role of public engagement approaches, with some students also discussing deficit approaches, public understanding of science, and scientific literacy models interchangeably:

> I had huge misunderstanding, I think before this course … I just divided scientists and public like a separate group and also, I think only about one way communication from scientists to public. And I thought that the main problem was the lack of knowledge in public. So yeah, now I understand that there are other approaches like public engagement and, public participation … it's like a new world for me now. Kira, FT, FG2, 2024.

Students frequently referred to a 'deficit approach' aligning with their perceptions of science communication prior to starting the programme or approaches that they had been taking in previous professional, voluntary or personal science communication roles, leading to moments of synthesis for some students:

> A moment of insight for me was the recognition and connection between of three separate points – 1. for a long period of time, communication of science was (and arguably still is) characterised by the deficit model [reference]. 2. This is despite the existence of clear evidence that there is no simple, linear path between availability of knowledge and the acceptance of that knowledge. 3. Trust in science and scientists is not particularly high in the world [reference]. Chanda, FT, RLJ, 2023.

That said we also noted that an appreciation of the weaknesses of the deficit model did not necessarily mean an unreserved embracing of public engagement approaches:

> Since learning about the participatory approach, I have felt a sense of relief that big, far-reaching organisations do take the time to engage with publics and involve them in a process through consultation and discussion, but I was sceptical as to whether communities do benefit … If the deficit model leads to mistrust between publics and experts as demonstrated in [reference], then surely the participatory model could too? … I think in theory the participatory model makes sense and there is evidence that it can benefit participants, but it probably needs to be assessed on a case-by-case basis. Kate, FT, RLJ, 2022.

> Although the dialogue model impressed me, I believe that both models (deficit and dialogue) can have a place in science communication. Approaches to communication technique selection along with quality evaluation should be developed for each activity separately, based on its aims. Kira, FT, RLJ, 2023.

We see students applying critical thinking to all science communication models and also considering how engagement can take place in practical settings, for example via public dialogues, engagement via museum exhibitions, and in informal learning activities with young people. Here, students talked about roles for evaluation and understanding of impact, and how engagement can lead to ownership. For instance, Samira (FT, FG2, 2024) discussed public engagement with an environmental project, whereby engagement extended beyond the short-term outcomes of a project as participants 'were taking ownership of dealing with it in their ways' and this then led to outcomes and results that arose much later in the process. This was just one example of overlap between threshold

concepts, as arguably this also links to co-production of knowledge, leading us to the next concept we identified in our data.

Co-production of science and society, making values a fundamental part of science

This was a slightly less prominent theme in our analysis and was also a threshold concept that had some overlap with notions of both public engagement and the role of trust. Nonetheless, we located numerous instances of students discussing the values of science, including how such values impinged on the motivations and deterrents for science communication by the scientific community, as well as individual scientists. These comments included recognition of the social context for science activities, a consideration of other types of knowledges (such as indigenous knowledge, traditional knowledge, myths, beliefs and superstitions) and how these both interfaced with science and were or were not valued by scientists:

> One of the papers that was actually referenced [in teaching] was about radioactive waste. Kind of radioactive issues in the Lake District in Cumbria and this kind of disconnect between communities and scientists because the scientists came in and kind of tried to impose their beliefs on the community and the community were kind of saying, 'well, actually, we've known this has been happening for years'. Tim, PT, FG2, 2024.

Co-production in this context was perceived to hold value but there was still a probing as to what that might mean in practice, and considerations around whose voice was most likely to be heard in such settings, including a recognition that science is not one 'monolithic entity':

> The image of science not as a single mass of land to be traversed, but a group of islands to be navigated through the water [reference] was a useful metaphor in furthering my understanding of some of the contemporary characterisations of science communication. Chanda, FT, RLJ, 2023.

> The co-production element, I think that is really kind of crucial for like changing perspectives because you realise that [they] sort of they feed into each other … You might if you're deep within science, you might have a tendency to think that it's separate from society. And if you're kind of quite far away, you'll think that sort of oh science is a thing people did, you know? But actually, the complexity of their relationship is, is um, yeah, I think changes perspectives. Jack, FT, FG1, 2023.

Jack described a change in his perspective, a recognition of the distance or disconnect that could sometimes take place between science, the scientific community and people. Once again, there were examples of students applying criticality to these models, for example, the role and importance of really listening was mentioned: 'I think so oftentimes that scientists listen to reply and listen to hear, but they don't necessarily listen to understand' (Amaal, FT, FG2, 2024). As such, a number of comments under this concept not only recognise how values impinge on science but how values, ethics and quality also play a role in science communication, and students' own future activities in this setting.

Trust

As discussed in relation to the previous threshold concept, trust was a topic that arose throughout our data, and whilst it was the concept for which we had the least number of coded extracts, it was integral to many aspects discussed and reflected on by students. These included discussions as to how trust should be a 'two-way process', that trust is not automatic, it is something that needs 'to be built' and earned on the part of both scientists and participants, and equally that trust is something that can easily be eroded and broken. In Focus Group 1, participants discussed the ways in which trust had different considerations in online and offline contexts, and that tools like AI were making it more complex to judge who to trust and who has credibility. There were also comments around the ways in which communication can diminish trust for instance via the use of 'clickbait' or a lack of transparency:

> I've seen a load of things about, information from the James Webb Space Telescope. But a lot of articles that are posting on it, they lead with these big kind of titles, but then when you actually start reading the article it

> it's not really about what the title is at all, they're just pushing an opinion or their own agenda. Stuart, PT, FG1, 2023.

In the case of this quote, Stuart was identifying with the experience of audiences or readers, in other cases examples provoked reflection as to how to build trust with communities and groups where lived experience may be very different from one's own. There were also examples in the reflective learning journals of students questioning their own identities. Students who had felt strongly connected to science described reading examples where there had been a loss of public trust and that this was now something they were understanding differently:

> It was hard to read that scientists could be viewed like this [negatively] and actually deserve it. But weeks later, revisiting this [reading], it is an inspiration to be better and a testimony to how much [science communication] has moved forward'.(Jodie, FT, RLJ, 2022)

Information that was initially seen to be challenging expanded students understanding of the different roles and influences on science communication: 'Although the complexities surrounding notions of understanding and public engagement are almost overwhelming, it is soothing to know that something as simple as "listening" and "mutual respect" does a great deal in fostering trust' (Amaal, FT, RLJ, 2023). In this sense, we see that trust is not only important to students learning, understanding this concept and how to obtain and appreciate trust, also forms part of the progression of their learning.

Now we turn to the two learning concepts, *learning progressions*, which featured in 10 of the 16 data files and to which 46 extracts of text were coded, and *communities of practice*, which also featured in 10 of the 16 data files and to which 41 extracts of text were coded.

Learning progressions

Learning progressions, the frameworks or pathways we have put in place to help students reasoning, development and expertise and to build the depth and nuances of their knowledge were integral to the focus group conversations, as well as the reflective learning journals. This included ways in which students referred to enhancing their theoretical understanding by exploring practical examples (for example, through a field trip to a local museum to explore concepts in reality), applying ideas 'hands on' in class and 'picturing things' via the use of analogies and metaphors. There were frequent descriptions as to how information was layered throughout the programme, and rather than feeling this created repetition, students discussed how helpful they had found it to have concepts cross-referenced in different teaching and that this enhanced their confidence:

> When you are at the beginning, a lot of concepts like the deficit model, I had no idea about and I found it really helpful, like learning through the lecture content but then doing the reading relays where we would read papers about that concept and discuss them with other people … .For me personally, that really helped to further understand the concept and then just hearing about it like further along like throughout the blocks, continuously learning about it. Elsbeth, FT, FG2, 2024.

> After having two or three, you know reading relays or self-directed reading, I was like ah, it makes sense now. Everything is coming together. It just kind of hammers you again and again about one topic and now the subject of the topic of deficit model is so deep, submerged in my head that I can just have a conversation [about it] with any of my friends anytime. Samira, FT, FG2, 2024.

In addition to reading relays (a group activity where students share thoughts on different articles), debates, tasks set between teaching blocks, and group work (particularly where groups were made up of students from different countries and perspectives) were also mentioned as being memorable in exploring diverse angles on concepts and arguments and enriching the student experience. Students described a sense of having a 'bedrock' of knowledge on which they could now build (Stuart, PT, FG1, 2023) and 'drill down' on (Tim, PT, FG2, 2024). The idea of a circular approach to knowledge chimed with many comments, and students discussed the ways in which the foundation of

understanding created in earlier modules, enabled them to engage with other concepts more readily when they were then introduced, though in some cases it had taken time to appreciate how knowledge would build: 'Looking back at this a few months later, in the early days of this Masters I thought I was supposed to understand everything already' (Jodie, FT, RLJ, 2022). Assessment played a role in students assessing impacts on their understanding, further contributing to their sense of progression. As with earlier comments, we also identified instances of students' pre-conceptions of science communication being challenged and extended as Jodie continued:

> I reread the first sentence at least 4 times and was already unimpressed, it was about hill farming in Wales … I wondered why lecturers chose such weird papers. I slowly became more interested, before long I was distracting my partner with my excitable opinions on science communication and how my life had been turned upside down from a book about farming. Jodie, FT, RLJ, 2022.

Community of practice

With comments surrounding learning progressions frequently focusing on shared and group activities, it is perhaps unsurprising to find that we also noted many examples of students developing a sense of an identity as a science communicator. What may be more surprising, since these are students who had applied for and were already studying a programme, is that a number of students acknowledged a lack of real awareness of what science communication was, either conceptually, as a field of practice, or disciplinary area, prior to starting the programme, as Jodie expressed:

> I think for me sort of even understanding that science communication itself was its own field within science, I know that seems really silly, but I just saw it as a way to, yeah, share science … Understanding [it as a discipline] with science and society just completely changed my entire perspective on what [science communication] is. Jodie, FT, FG1, 2023.

Students described having little understanding of the policy context for science communication, awareness of the range of possible career options, or the number of disciplines on which science communication draws prior to the programme. Expanding their awareness of the breadth of the field was 'exciting' and students described coming to appreciate 'science communication as an individual field that can be implemented into so many different areas' (Stuart, PT, FG1, 2023), or it being 'astonishing to witness [science communications] deep roots permeating into every other possible industry and opening many other opportunities' (Samira, FT, RLJ, 2023).

As the programme encourages entrants from a range of different disciplinary backgrounds, community seemed particularly important. Students frequently described a sense that they did not offer the same skills set as their peers but that the collaborative nature of the programme allowed for this to be reconciled, identifying benefits from peer feedback, discussion and appreciating peers having 'completely different interpretations' (Tim, PT, FG2, 2024), with this being important for their own learning:

> I felt a sense of imposter syndrome with regards to my academic skills. However, after drawing upon the online materials in tandem with wider reading, I was able to recap the main concepts to my peers. The group element of the task was more affirming. Hearing the experience of others and gaining an overview of several key texts, enabled me to categorise learning resources in terms of entry level to greater depth. Rebecca, FT, RLJ, 2022.

> To prepare we met as a group. This made me anxious, and I experienced imposter syndrome … I was comparing myself to the others who all have 'hard' science backgrounds. I had to remind myself that [discipline] is science, and I earned my place on the course by undertaking a rigorous piece of scientific research. Betsy, PT, RLJ, 2023.

Whilst students cultivated a sense that they could be part of the science communication community, there was sometimes a questioning as to how this then related to their previous academic backgrounds and identities. For those already in professional practice, studying part-time, it could prompt a questioning of long-held beliefs and approaches, and in the focus groups particularly,

students discussed being unsure as to whether they could yet describe themselves as a 'science communicator':

> I think this has been one of the biggest problems I've had so far. Like, how do you identify as a science communicator? You know, do I need to do a degree? Is it like a Masters, or is it a PhD, and when do you call yourself a science communicator then? … But I think now I'll be more comfortable saying that I am a science communicator because I've taken the Masters. I don't know if that makes sense? Because I feel now I have credibility to say that. Amaal, FT, FG2, 2024.

We see then, the programme empowering students and giving them confidence to identify themselves as a science communicator, albeit with some trepidation, as well as embracing an increased understanding of both what science communication can be as a field and the breadth of activities it can involve.

Finally, beyond the concepts we have discussed, we coded 47 extracts of text, from 14 data items to a code which we described as '*other*'. This code contained several concepts or topics mentioned in passing in the reflective learning journals, as well as responses to questions where we specifically probed if any concepts were missing in the focus groups. We noted discussion of the 'Two Cultures' debate, theories of formal and informal learning, ethics, the role of storytelling, fake news and mis/disinformation.

However, by far the most dominant topics for exploration were '*inclusivity and accessibility*' including discussion as to how race, ethnicity, social class, and social capital can mean some communities are underserved by science communication, through to recognition of the Eurocentric nature of science communication histories and science communications tendencies to focus on framings from the Global North:

> A key point and something I've found to be of importance, however, is inclusivity of science communication [references]. Science for some time has been cast as a Eurocentric affair and often a male endeavour [references]. This narrow-minded view needs to be moved away from if the field of science communication is wanting to incorporate all members of a community. Stuart, PT, RLJ, 2022.

> It is important to recognise that scientists do not possess all the answers and that their knowledge may be limited to their specific expertise [references]. I realise that it is crucial to involve diverse groups into the discussion, from various backgrounds and who share different perspectives and opinions. Inclusivity will enhance the overall quality of the debate and ensure that a more well-informed decision is reached. Elsbeth, FT, RLJ, 2024.

A second key area that arose in relation to our focus group questions, was the role of threshold concepts in students own learning. We asked if it was a framework or theory that it would be helpful to be aware of. Whilst students could see the value of the concepts, particularly to educators and as a reflective prompt, they didn't view the idea as something necessarily useful to them: 'some things don't need to be labelled, you go with the flow and assess it as per your own learning curve and your progress' (Samira, FT, FG2, 2024). However, in both focus groups, students discussed the value of the conversations we had held, that it had been useful to sit and reflect together as a group, and that this had been beneficial to capture their learning, whilst we as teaching staff on the programme also found both data collection and analysis a very insightful opportunity to reflect on our teaching approaches and further understand our student experiences.

Discussion

> No one trainer can be an expert for all science communication environments and not all activities can or should be taught in one course. (Lewenstein & Baram-Tsarabi, 2022, p. 14)

Although the relevance of the concepts discussed in Lewenstein and Baram-Tsabari's (2022) article had been clear to us as science communication educators at the outset of this research, we were surprised by the sheer quantity of content we were able to identify and code in relation to these concepts in our thematic analysis, particularly in the reflective learning entries, where we had

not specifically probed or questioned students on these concepts as we had in the focus groups. In response to our research questions, we find that all four threshold concepts, as well as examples of the two learning concepts can be identified in students reflective learning entries at UWE Bristol and these were also concepts that were seen to be useful and important to students within the focus group conversations, albeit students did not see a need to explicitly label threshold concepts in relation to their own learning.

Whilst our students could see the value of threshold concepts in underpinning their science communication education and training, and they were playing an important role in their reflective practices, they did not identify a need to articulate them in this way, though it would be interesting to consider if this response changes as students graduate the programme, and progress in their careers or employment opportunities. Nicola-Richmond et al. (2018) discuss how some threshold concepts may be transitional until a student is immersed in practice, and we would be interested to undertake data collection with students' post-graduation to further understand the longitudinal impact of these concepts and learning experiences on their science communication careers. We also foresee opportunities to continue this research with future cohorts in years to come, as well as communities that employ our students to understand the importance of threshold concepts to them (Barradell, 2013).

The main gap in conceptual understanding that we identified was associated with inclusivity and accessibility, and there could be many reasons for this. This is an area of our teaching that we have considerably strengthened over recent years, and to which we have found our students, who themselves represent diverse communities in terms of race, ethnicity, age, sexuality and gender, seem to have particularly responded to. One aspect of threshold concepts which is tricky, is overlap, and it could be argued that these concepts are integral to notions of *audience-centred communication* and we also recognise that Lewenstein and Baram-Tsabari (2022) identify such points (e.g. that students understand and try to act on issues of equity, inclusion and diversity in science communication) within a number of strands of their learning objectives, as well as other important concepts that our students raised, like ethics, quality and credibility. Therefore, there is a question mark as to whether inclusion as a concept may increasingly warrant more conceptual recognition, or whether this is simply a result of these topics becoming increasingly embedded rather than peripheral aspects of our teaching at UWE Bristol. Previous research has highlighted that there can be little to gain by arguing whether something is or isn't a 'threshold' or 'concept' (Quinlan et al., 2013), and we simply signpost this for attention here. It would suggest that greater global diversity could be reflected in the framework and the cultural perspectives it represents, as McKinnon (2024) also argues in this special issue.

There are a number of limitations in this small-scale study, which could easily be addressed with a more extensive piece of research. We conducted our analysis of reflective learning journals at a point when students had only completed one module as part of their M.Sc. programme. Therefore, whilst we did find evidence of threshold concepts, undertaking research at a later stage of the programme and/or across all modules would allow us to provide a more detailed picture of their prominence, as has been suggested in previous work with educators (Nicola-Richmond et al., 2018). Focus groups to some degree assisted here. We were able to probe and discuss threshold concepts with students, including those who were part way through or had completed the majority of taught content in the programme, but nonetheless these students did not have distance from their experiences, or necessarily opportunities to further deepen or recognise the value of their knowledges. Case studies we have been gathering in conjunction with graduates of our programme, do anecdotally suggest many of these concepts remain pertinent to them post their studies with us (Science Communication Unit, 2023) and Barradell (2013) also highlights that threshold concepts can be harder to look back on once attained, due to their irreversible nature, but it is important to highlight we captured reflections part way through the programme experience.

We also did not conduct any comparison of the students' contributions to reflective learning journals and focus groups with their performance on the module and programme, and whilst

this may bear no relationship it is possible that students were more likely to engage in the research if they were performing highly in terms of their assessments and felt confident in their understanding of concepts. As we addressed via our ethics process, there are hierarchical issues in conducting research of this nature, which may have been increased if assessment grading was also considered in the context of our data analysis. By separating assessment processes from the research itself, we were able to facilitate the focus groups constructively and compassionately and with a sense that students enjoyed and benefited from the conversation as equals:

> I think it's really helpful just having lecturers who treat you like people. Cause I think it's sometimes it's so easy to have the like teacher and student dynamic, where it's just they tell you things. But it's like having those conversations and understanding how it works properly has been really helpful. Stuart, PT, FG1, 2023.

However, the strong presence of relevant content in the data we gathered also suggested threshold concepts underpin a number of our assessment approaches within our programme and the Science and Society module in particular (Nicola-Richmond et al., 2018; Timmermans & Meyer, 2017) and further research could probe the relationships between the learning of concepts and assessment performance.

Our research supports the notion that not all learners experience threshold concepts in the same way or at the same points in time (Meyer, 2012; Nicola-Richmond et al., 2018; Timmermans & Meyer, 2017) but suggests there are some considerable shared core experiences, at least amongst this relatively small cohort of students who participated in our research at UWE Bristol. We also see qualitative evidence of the ways in which this can lead to transformational shifts for learners, create uncertainties, counter understandings, expose connections and increase a sense of criticality towards science communication as students sit in a somewhat 'liminal' state, sometimes as insiders in science communication, sometimes not (Cousin, 2006; Lewenstein & Baram-Tsarabi, 2022; Meyer & Land, 2006; McKinnon & Vos, 2015). We also identify evidence that an understanding of threshold concepts, and the learning processes that underpin some science communication programmes, can assist students to consolidate their identities to some degree, particularly when working with diverse groups of peers but we also appreciate that science communication itself has rarely consolidated its boundaries (Trench, 2023).

Acknowledgements

We would like to thank the students, and soon to be graduates, who participated in this research and consented to being named in the acknowledgements as follows: Aarushi Tanwar, Alan Williams, Aleksandra Peliushkevich, Ed Dixon, Florrie Dingley, George Edwards, Izzy Liney, Jen Weston, Louis Davies, Magaret Sivapragasam, Rianna Green, Ria Griffiths, Sarah Adams and Sneha Uplekar. Wilkinson contributed to a 'member check' of Table 1 in Lewenstein and Baram-Tsabari (2022) but this predated any invitations to respond to the article or conceptualisations of this research.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethics statement

This research was approved by the university ethics committee at UWE Bristol (HAS.23.05.117). Our ethical approval permitted us to use a student's real name in the acknowledgements of this article (with their consent) but required the use of pseudonyms with the data itself.

Funding

This work was supported by the University of the West of England.

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