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Bringing science communication skills into the university classroom and back out again: What do palaeoscience educators think?

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University-level pedagogy and public science communication both have the same broad goal: to facilitate the sharing of knowledge and understanding from a specialist or expert, to a non-specialist group. Recent research has emphasised the need for there to be a two-way transfer or dialogue of ideas between these fields, but collaboration thus far is rare, particularly at the tertiary education level. Performing science outreach is mostly a voluntary service for academics, and institutions provide little in the way of support, training or recognition. Here I explore the potential for a positive feedback loop between science communication and higher-education pedagogy in the palaeosciences. A synthesis of best practises in science outreach is drawn from the literature and related to pedagogical concepts and findings. The resulting congruences suggest enormous potential for 'cross-pollination' of ideas between the fields. However, in-depth one-on-one interviews and focus groups with palaeoscience educators, as well as an online survey, indicate that this potential remains largely untapped in the palaeosciences community. While respondents could identify certain skills as being integral to success in science communication, they did not appear to realise that the same skills, when applied in the classroom, could contribute towards key challenges in higher education today, including the stimulation of student engagement and motivation, the accommodation of an increasingly diverse student body, the anticipation of common student misconceptions in science, and the improvement of pedagogical models of delivery. Another emergent theme was that being a good science communicator was "much simpler" than being a good teacher, conflicting with evidence-based pedagogical and outreach research. While many palaeoscientists did express strong commitments to science communication, they had previous experience of time constraints and conflicts with other academic responsibilities. Therefore, both palaeoscientists and their institutions would benefit from viewing science communication as a valuable and formally rewardable activity within the scholarship of sharing knowledge, which also contributes to other aspects of a successful academic career.

KEYWORDS

pedagogy, outreach, palaeontology, engagement, diversity, anticipating misconceptions, active learning

Introduction

University teachers are expected to fulfil a number of complex and diverse roles (Harden and Crosby, 2000). In conjunction, the majority also have research, service, and administrative duties. This creates a substantial amount of pressure on the modern academic: how to juggle these roles in order to meet their commitments and achieve maximum productivity?

Academic performance management policies are intended to provide guidelines for this (Kenny, 2017), but some duties, despite being considered by the academic community as a key part of academic life, remain undervalued by institutions. One such duty is science communication, also referred to as "outreach" or "community engagement." Often, this is carried out on a voluntary basis, with little to no formal training, recognition, or reward (Rodari and Weitkamp, 2015; Illingworth et al., 2018), and yet, the case has been made repeatedly that all scientists have societal responsibilities to communicate their science to the public (Eron, 1986; Sagan, 1989; Greenwood and Riordan, 2001; Leshner, 2003; Knudsen and de Bolsée, 2019). Studies (e.g., Peters et al., 2008; Casini and Neresini, 2013; Loroño-Leturiondo and Davies, 2018) indicate that many scientists accept this personal responsibility and want to create positive experiences for their audiences, but only under certain conditions: scientists must believe they will enjoy the interaction, make a positive impact, and have the time to engage (Besley et al., 2018).

There are many excellent reasons for STEM (science, technology, engineering, and mathematics) academics to perform science communication on a regular basis: it is often the only way the public learn about scientific breakthroughs that affect society, it provides communities with information necessary to make decisions about science policy, it can be viewed as returning a debt of taxpayer-funded support and encourage long-term funding for science, it stimulates the next generation of scientists, transfers technology to end users, improves network and institutional prestige, and not least, provides personal satisfaction to the scientists performing it (Gascoigne and Metcalfe, 1997; Treise and Weigold, 2002; Peters et al., 2008; Davies, 2013).

Unfortunately, the reality is probably quite different: previous research identified that scientists who undertake science communication or outreach (hereafter referred to as "scicomm") frequently face institutional and professional impediments, and are rarely rewarded for the service (Gascoigne and Metcalfe, 1997). This is still not adequately addressed (e.g., Royal Society, 2006; Bickerstaff et al., 2010; Neresini and Bucchi, 2011; Davies, 2013; Hamlyn et al., 2015), possibly because formally standardised and comprehensive frameworks for evaluating scicomm success are not yet commonly implemented in higher education institutes (Neresini and Pellegrini, 2008). Support frameworks for engaged research (e.g., Holliman et al., 2015; Holliman and Warren, 2017; Holliman et al., 2018) are an exception, but for this to become the norm, these authors state that ongoing "buy-in" is still required at all levels, from individual researchers to universities, funders and policy-makers. Although many funding bodies are beginning to specify "community engagement" or "public dissemination of results" as a requirement for receiving grant money, it remains unclear how scientists must balance these activities with expectations of ever-increasing academic outputs (Davies, 2013; Müller, 2014).

How then, can scicomm become more personally and professionally rewarding for scientists in the current academic climate? Boyer (1996) argued that academia underwent a fundamental change in the last century, with research continuing to be highly prized, university teaching becoming increasingly valued, but with a concurrent large decline in the commitment to what he terms the "scholarship of engagement." This led to a progressive disconnect between academic research and the broader public discourse. To rectify this, Boyer maintained that universities must broaden the scope of scholarship as it currently stands to a scholarship of engagement comprising four pillars:

- A scholarship of **discovery** (focused on primary research).
- A scholarship of **integration** (placing specialised research within an interdisciplinary context).

- A scholarship of **sharing knowledge** (communicating and teaching research to peers, students and the public).
- A scholarship of **application** (moving knowledge from theory into practise, and from practise back to theory).

Here I make the case that academia could reframe its view of teaching, scicomm and service as distinct and often competing responsibilities, to a more holistic commitment to "sharing knowledge" in the spirit of Boyer. This could be of particular value in the palaeosciences, a subject that has captured the attention of the public since the North American "Bone Wars" of the late 1800's, a ruthless competition between two palaeontologists, Cope and Marsh, to discover the most fossils. Contemporary movies and books have embraced diverse aspects of palaeontology such as dinosaurs, mass extinctions, and the evolution of apes, popularising them to a global audience. But arguably the greatest contribution palaeosciences makes to modern society is not entertaining people, but contributing to fundamental research in climate change. As the Earth system is now well on its way to experiencing climate states not seen for millions of years, this creates an increasing need for palaeoscientists to go back deeper in time for appropriate future climate analogues. How this research is shared with future scholars, industry and government, and the broader public, is thus of paramount importance, and argues for increasing commitment to, and flexibility in, communication approaches.

A first step towards this transformation involves understanding how palaeoscientists view and experience the sharing of knowledge in their discipline. Here I used three different modes of data collection, an in-depth one-on-one interview, a focus group, and a public survey, to investigate the perceptions and attitudes of palaeoscience educators regarding the relationship between science communication and higher education. "Scicomm" was defined in the broadest sense (following McKinnon and Vos, 2015): by its overarching aim of connecting science with the general public. This concept is well-illustrated by the diverse scicomm ecosystem model of Longnecker (2016, Figure 1). Here it encompasses different aspects of the field such as "public awareness of science" (PAS), "public engagement in science" (PES), and "public understanding of science" (PUS) (Burns et al., 2003; Cheng and Shunke, 2008). It includes "traditional" scicomm engaged in by academics, such as media interviews, press releases/popular science articles, and public or school speaking engagements, as well as "modern" scicomm that relies on the internet, mainly in the form of social media, podcasts, etc. This includes both formal (e.g., schools, universities, science museums) and informal (e.g., media, recreational activities, outdoors) learning environments (Bell et al., 2009 and refs therein).

Specifically, I chose to investigate: (1) whether palaeoscientists saw any relationship between university teaching and scicomm, (2) which barriers prevent the sharing of knowledge in both fields, (3) if palaeoscientists see shared competencies in scicomm and teaching, both general and specific to palaeosciences, (4) and whether these shared competencies could contribute to key challenges in higher education. These results are integrated within a theoretical framework of previous studies across STEM disciplines. Together this indicates that for many aspects of teaching and scicomm, there are opportunities for "cross-pollination" but these remain largely unrecognised or underutilised both by individual academics and their institutions.

Making the case for the teaching-scicomm relationship

This section describes the theoretical basis for viewing teaching and scicomm under a broader umbrella of "sharing knowledge" (Boyer, 1990, 1996), and support for a relationship between the fields from a growing body of STEM-focused literature. Cloître and Shinn (1985) and Bucchi (2008) argue that scicomm should not sharply divide hard science and popular science, but rather utilise a "continuity" model of scientific communication. Along this continuum, a diversity of communication styles and contexts can be employed, which can be categorised into four main stages: popular, pedagogic ("textbook" science emphasising historical perspectives and the body of scientific knowledge), interspecialist (e.g., interdisciplinary publications in Nature or Science), and intraspecialist (e.g., publications in specialised journals). These same main stages can apply to a trajectory of scientific ideas (Bucchi, 2008), and can also be employed in a higher education context. By sharing knowledge using a continuum of scientific understanding, students from a diversity of backgrounds and at various skill levels are not alienated (Figure 1). Furthermore, the valid existence of both lay knowledge and expert knowledge is acknowledged in this model, rather than being viewed as an information gap (Wynne, 1995; Manyweathers et al., 2020). It is valuable to remember that all intraspecialists also possess lay knowledge, particularly if working in cross-disciplinary fields. Finally, there must be a two-way exchange of ideas in order to achieve active citizen and student engagement.

There are a limited number of publications (e.g., Cheng and Shunke, 2008; McEwen et al., 2014; McKinnon and Vos, 2015; Matthews et al., 2017) that encourage cross-collaboration between scicomm and pedagogy and, but in these works, pedagogy is generally used with the primary (typically the first stage of formal education) or secondary (following on from primary education and preparing for vocational/tertiary education) school perspective in mind. An exception to this is the rubric developed by Sevian and Gonsalves (2008), which distinguishes between the content knowledge and pedagogical knowledge of scientists at the tertiary level (education at universities/colleges) and higher. Characteristics of adult and younger learners in formal education can differ

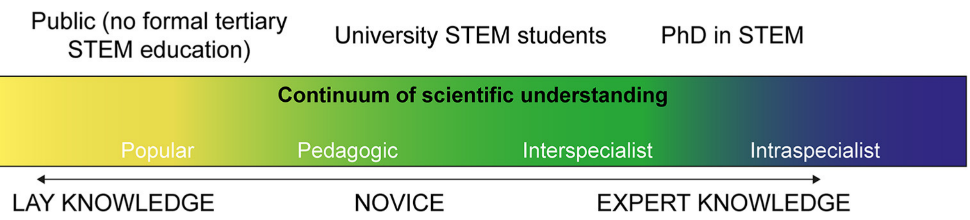

FIGURE 1
An integrated model of the pedagogic–scicomm continuum, showing stakeholders, the various levels at which science can be transferred, and kinds of knowledge that can be incorporated. Different stakeholders tend to fall at different points across the gradient, but it is important to recognise that they never form discrete and separated groups (drawn using concepts from Cloître and Shinn, 1985; Bucchi, 2008; Petcovic and Libarkin, 2007).

significantly (Caffarella and Barnett, 1994; Cercone, 2008), for example in that adults are more likely to enter educational programs voluntarily, manage their education around other responsibilities, and are more motivated and task-oriented. Accordingly, in this paper I focus specifically on the links between scicomm (at the level of upper secondary school or higher) and pedagogical principles that are applicable to higher education.

There are a number of excellent publications in the literature with tips for being a successful science communicator across these contexts, based upon detailed observation of scicomm taking place in different contexts, and sometimes personal experience of performing it on an ongoing basis. These papers have been used to produce a synthesis of best practises in scicomm, which are then linked with a review from the literature of corresponding examples from STEM pedagogy (Table 1). It can be seen that for the majority of key components of a successful scicomm experience, there exist related or similar principles applicable to teaching at the level of higher education, so-called "shared competencies." These can be summarised within four different themes, all of which have been shown to present particular challenges in higher education. However, their applicability to the palaeosciences in particular has received little attention to date.

Engagement and motivation

Scicomm and formal science education both have the same main goal: to engage their target audiences in science (McKinnon and Vos, 2015). Engagement can be defined as a threshold concept for both fields (Cousin, 2010; McKinnon and Vos, 2015), the latter of which is a process of identifying key ideas that are fundamental to a discipline. According to this definition, engagement is thus pivotal to success in both scicomm and science education, but they also face the same major challenge: science may not be intrinsically motivating to either a public or student audience (McKinnon and Vos, 2015; Knudsen and de Bolsée, 2019). Even when university students have chosen to enrol in STEM courses, they may not be intrinsically motivated (Bartle et al., 2011) because this quality has been found to decline as students progress from primary to tertiary education (Sheard et al., 2010; Leach and Zepke, 2011; Abeysekera and Dawson, 2015).

Stimulating intrinsic motivation requires students to find satisfaction, relavance, and personal connexion in learning, which in turn improves their level of engagement (Pugh et al., 2009; Rifkin et al., 2010; Abeysekera and Dawson, 2015; McKinnon and Vos, 2015). Good science communicators are experts at engaging their audience, by purposefully crafting messages that are relevant, interesting, and present science at a level of detail that audiences can grasp (Kapon et al., 2010; Longnecker, 2016; Knudsen and de Bolsée, 2019).

Accommodating diversity

Student bodies in higher education are becoming ever more diverse with respect to age, language and cultural background (Morgan, 2013; McEwen et al., 2014). Informal science educators are experienced at conveying science to a wide range of learners with differing backgrounds, interests, and abilities (Hestness et al., 2017), and therefore university teachers who are also experienced science communicators are likely to be more aware of this characteristic in their classes. Furthermore, in both formal and informal educational settings, scientific knowledge must undergo some degree of translation. Scicomm training and practise can develop the flexibility to pitch science at various levels, while still keeping the underlying science solid (Gregory and Miller, 1998; Sevian and Gonsalves, 2008; Watermeyer, 2010). Kapon et al. (2010) refer to this as TSE (Translated Scientific Explanation), and practising scientists with strong skills in scicomm are experts in creating TSEs.

University teachers who are already proficient in scicomm can probably better (a) communicate their science clearly without overreliance on as-yet-unfamiliar jargon or too much technical background, and (b) accommodate different

TABLE 1 A synthesis of best practices in scicomm (adapted from Sevian and Gonsalves, 2008; Bell et al., 2009; Kapon et al., 2009; Somerville and Hassol, 2011; Baram-Tsabari and Lewenstein, 2013; Knudsen and de Bolsée, 2019; and refs therein; Longnecker and Gondwe, 2014; Longnecker, 2016; Olson, 2018; Fleming et al., 2020; Wilkinson et al., 2020; Olson, 2021; Longnecker, 2022) and their relationship with pedagogical findings or examples applicable to higher education.

Key components for successful scicomm	Links with pedagogical findings/examples
Establish security through a familiar setting, format and language	• Social contexts that nurture a sense of security and relatedness foster intrinsic motivation, and thus engagement, in students (Niemiec and Ryan, 2009; Van Nuland et al., 2012)
Select appropriate content; make the message relevant to audiences	• Contextual teaching gives meaning to mathematics because "students want to know not only how to complete a mathematical task but also why they need to learn the mathematics in the first place. They want to know how mathematics is relevant to their lives" (Williams, 2007, p. 572) • Engaging chemistry students in realistic decision-making and problem-solving activities fosters useful transferable skills (Talanquer and Pollard, 2010) • Giving students real world, "messy" data improves their data analysis skills (D'Avanzo and Morris, 2008) • Case studies that highlight real-world societal issues and applications across a range of STEM subjects are more effective than other methods of content delivery (Bonney, 2015)
Prioritise clarity, simplicity, and good organisation of material. Focus on a few main points	• Giving students too much information risks deskilling them; rather teach how to judge the quality of information (Boud, 2001) • Deeper conceptual understanding of a minimum core of fundamental ideas is preferable to superficial coverage of many topics (Talanquer and Pollard, 2010) • Clarity and simplicity are particularly important for nurturing a diverse student body that may include non-native English speakers (Woolston and Osório, 2019)
Repeat your main points (in different ways)	• The "spiral of knowledge" model encourages teachers to revisit concepts as students build knowledge progressively (Barrett, 1985) • "I see the need to repeat, repeat, repeat some concepts. Scientists take for granted the 'glasses' through which we see the world, and our students often lack those glasses" (D'Avanzo and Morris, 2008, p. 43)
Use appropriate examples, analogies, metaphors and visualisations to explain complex topics. Anticipate common misunderstandings	• Visual representations are powerful cognitive aids in understanding life sciences. Ambiguities, simplifications, and potentially misleading elements in visualisations cause difficulties for students, possibly (mis)leading them to alternative interpretations (Schönborn et al., 2002; Cook et al., 2008; Rundgren and Tibell, 2010)
Acknowledge and show respect to multiple worldviews	• STEM students need to become comfortable with nuance, uncertainty and debate, all of which have specific meanings in scientific discourse (Editorial, 2019; Gerrits et al., 2021)
Expert knowledge is essential, but passion and personal connexion are key for the audience to absorb it	• Students must find a learning activity inherently satisfying in order to feel to intrinsically motivated (Abeysekera and Dawson, 2015) • Students' emotional state and feelings of intensity is a central factor in their overall level of engagement, which is critical for learning (Pugh et al., 2009; McKinnon and Vos, 2015) • Students must find personal meaning in their material, else learning is "a perplexing, futile process" (Rogers, 1969)
Engage in dialogue, solicit feedback, and create opportunities for audience participation	• Active learning approaches and collaboration give students a sense of autonomy and responsibility for their own learning, thus improving performance (Handelsman et al., 2004; Freeman et al., 2014; Jones et al., 2015). A deep learning approach promoting active understanding and self-production of knowledge can result in improved student outcomes, grades and retention of knowledge (Bartle et al., 2011; Pegrum et al., 2015)

levels of knowledge and skill development within a singular learning setting. Thus, it is likely that scicomm skills can assist in fostering a more diverse and inclusive student body in higher education settings, a pressing issue that has also been highlighted within science communication itself (Dawson, 2014; Davies et al., 2021). In pedagogy and scicomm alike, engagement with new knowledge is influenced by the audience's existing social norms, values, beliefs, attitudes, understanding, skills and behaviour; thus, effective knowledge sharing must consider diverse audience identities as central to success (Longnecker, 2016, 2022).

Anticipating misconceptions

Many tertiary STEM students enter the classroom with deeply-rooted misconceptions about fundamental concepts

(Duit and Treagust, 2003; Kind, 2004; Duit, 2007; Shaw et al., 2008; National Research Council, 2012 and refs therein; Wright et al., 2014). Almost 40 years ago, Andrea diSessa described a mechanism by which this can operate—the so-called p-prim, short for phenomenological primitives (diSessa, 1983). This is a cognitive shortcut to problem solving, also referred to as "intuitive knowledge," which is often not reliable. Research on conceptual change strategies to address misconceptions such as p-prims has been ongoing since the 1970s (e.g., Duit and Treagust, 2003).

Experienced science communicators who invite dialogue with their audiences soon discover common misconceptions that the public have about their subject, and become aware of how inappropriate visual aids and explanations can trigger mistaken ideas (Kapon et al., 2010). Thus, university teachers who also practise scicomm regularly may have greater cognisance of specific misconceptions in their subject, and how to avoid or address them upfront in the classroom.

One pedagogical solution for addressing misconceptions is the use of "bridging analogies," which function by linking a correct understanding that students already have, with the incorrect idea. Practising scientists who are also excellent science communicators use analogy as a primary device for translating science to an appropriate level, especially because the audience may lack prior knowledge on the topic (Kapon et al., 2010).

Flipping the model of delivery

Pedagogical research in STEM learning confirms that active learning approaches are superior to passive learning in terms of student performance, and yet there remains resistance towards widespread implication of inquiry-based pedagogy (e.g., Handelsman et al., 2004; Davies, 2008; Freeman et al., 2014; Jones et al., 2015). Similarly, the diffusionist (deficit) model in scicomm remains popular (Besley and Tanner, 2011; Cortassa, 2016), which operates by assuming a public knowledge deficit. When this model is applied, the primary goal becomes simply to provide the missing facts, assuming the audience will accept them, and no return flow of knowledge is expected (Bucchi, 2008; Davies, 2008), nor are other valuable sources of knowledge considered (Longnecker and Gondwe, 2014). Yet, the diffusionist model persists, possibly because it represents an intuitive and reassuring solution to the "obstacle" of scientific illiteracy (Cortassa, 2016).

However, awareness of the diffusionist model's shortcomings is growing because scientists have realised that scicomm on topics of global importance, such as climate change, has been largely unsuccessful to date (Knudsen and de Bolsée, 2019). This is partly because own values, goals, beliefs and contexts, along with scientific facts, shape individual perceptions and understandings in the public mind (Wynne, 1995; Bucchi, 2008; McKinnon and Vos, 2015; National Academies of Sciences Medicine, 2017; Illingworth et al., 2018). Competing models of scicomm and pedagogy are thus a mirror of one other, and by incorporating lessons learned from unsuccessful scicomm (which are often immediately apparent in controversial subjects such as evolution or climate change), university teachers may adopt more hands-on, student-centred practises in pedagogy.

The shared competencies discussed above are in line with an increasing body of literature advocating for improving the connexions between scicomm and pedagogy. Sevian and Gonsalves (2008) found that scientists with pedagogical training are better at explaining their science. Cheng and Shunke (2008) advocated that science communication and science education are closely related through the common goals of improving scientific literacy and fostering a congenial relationship between science and society. McEwen et al. (2014) found that role-play experience in scicomm provides lessons for role-play pedagogies in teaching university-level geography, particularly with regard to increased learner diversity in classrooms. Patrick (2017) remarked on the many pedagogical practises that both informal science communicators and university educators need to employ, such as organising and structuring lessons, defining clear lesson objectives, engaging and managing behaviour of students, and reflecting on their teaching practises.

Hestness et al. (2017) showed comparable goals for out-of-school and in-school learning outcomes, such as: sparking interest and abilities to explain phenomena in the natural world, understanding and generating science knowledge, engaging in scientific reasoning, reflecting on science, engaging in scientific practise, and identifying with the scientific enterprise. Matthews et al. (2017) proposed that "understanding how and why people learn and want to learn and what they want to learn are all important theoretical concepts that are applicable to both schooling and informal science learning" (Matthews et al., 2017, p. 384). The authors suggested scicomm practises that should be incorporated for formal science education, such as free choice learning and exploration of and in nature. Mercer-Mapstone and Kuchel (2017) identified from a literature critique that common communication skills align across the fields of science, communication, education, and science communication. Further works indicating that scicomm or informal learning does and should play a substantial role in formal science education include studies by Stocklmayer et al. (2010), Fallik et al. (2013), Avraamidou (2014), and McKinnon and Lamberts (2014). Accordingly, the potential for a dialogue of ideas between these fields certainly exists, but do palaeoscientists who teach at university level recognise and/or take advantage of this potential, and how is it particularly applied within this discipline?

Methods

Data from an in-depth one-on-one interview, a focus group, and a public survey were collected (mixed methods approach), to reach a wider and more diverse audience and enhance trustworthiness of the findings. All participants were selected for (or self-declared, in the case of the public survey) their experience in teaching and scicomm in palaeoscience-related disciplines, and gave written informed consent before participating. No ethical approval was requested as the Swedish Act concerning the Ethical Review of Research Involving Humans (2003:460) states that studies involving adults using informed consent require ethical approval only if a method is used with the potential to physically or mentally influence a person, or if they involve sensitive information that can be traced back to individual people.

One-on-one interview

A 1-h long interview was conducted with a palaeoscience academic who is practised in both university teaching and outreach to the public. Open-ended questions (following Bryman, 2016) were asked about their experiences with teaching, scicomm activities, and how they felt the two fields are or could be related. Questions centred around successes, challenges, and innovations in teaching and scicomm, as well as personal experiences of necessary skills and techniques in both arenas, and how these skills could be developed. The full list of questions is provided in the Supplementary Information (A).

Focus group

An online focus group was held comprising seven scientists and science communicators, who specialised in climate and/or palaeoclimate science and spanned different career stages (all part of the outreach group "*Climate Answers by Scientists*," run by the Bolin Centre for Climate Research, Stockholm University). Participants had all expressed a previous commitment to public science communication and outreach ("scicomm"), and also had experience of teaching.

The intention of the focus group was to explore opinions and perceptions regarding the following hypothetical statements:

a) whether university teachers with good pedagogical skills can be predicted to be more effective popular science communicators than teachers who lack pedagogical skills, and
b) whether university teachers with good popular science communication skills can be predicted to be more effective teachers than teachers who lack science communication skills.

The focus group was semi-structured and run in accordance with principles summarised in Longhurst (2003): predetermined questions were verbally directed to the focus group participants, but the discussions were allowed to unfold in an informal, conversational manner where participants could reply to the interviewer and also discuss answers with each other, or ask new questions. The interviewer kept the group on topic but was otherwise non-directive. In total, the focus group lasted for ∼20 min and ended when the participants decided they had nothing further to discuss. Conversations from the one-on-one interview and focus group were recorded and transcribed automatically using Otter.ai© software (https://otter.ai).

Survey

A public survey was distributed *via* the internet through a global mailing list of palaeoscientists (PaleoNet.org) and by email to a database of colleagues employed on 5 continents. The aim was to gain diverse responses with regard to country and cultural background. Two email reminders after the original survey mail were sent out to boost the response rate, and in total the survey was sent to ∼2,200 people, of which 112 responses were obtained. This represents a 5% response rate. Answers were gathered anonymously through an online survey tool (Artologik Survey&Report) *via* Stockholm University's secure servers. The survey was restricted to palaeoscientists with a Master's degree or higher who had taught students at university level.

The survey was designed to be completed within a maximum of 15 min. Before beginning, participants were asked to consent that their personal anonymised data be collected and used for the purposes of the project. First, demographic questions on career and gender were asked, with multiple choice answers and a free text alternative. The second part of the survey asked about successes, challenges, and time allocated to university teaching of palaeoscience-related subjects. The third part of the survey asked about successes, challenges, and time allocated to science communication/outreach of palaeoscience-related topics. The fourth and final part of the survey asked for opinions on the same hypothetical statements presented to the focus group (Section Focus group a, b). The full text of the survey questions and answers to demographic questions are contained in the Supplementary Material (B and C, respectively).

Data analysis

Transcriptions from the one-on-one interview and focus group were edited for errors and clarity (removing instances of "um," repeated words, etc.), and particularly relevant statements and those suitable for quotation in the text were noted at this initial stage. Next, texts from the one-on-one interview and focus group were individually coded by starting with a set of preliminary deductive conceptual codes (following Miles and Huberman, 1994) from the literature. Codes were then refined upon review of the data, following the inductive approach (Glaser, 1992), verified by another researcher, and reviewed again, producing an integrated approach for code structure. Thematic analysis followed the approaches of Bradley et al. (2007) and Braun and Clarke (2006). Although the one-on-one interview and focus group texts were coded separately, the themes and subthemes emerging were extremely similar. These results are thus aggregated in Section Thematic Analysis of the One-on-One Interview and Focus Group and combined into a single thematic map (Figure 2). Survey answers were represented visually, and free text answers coded and summarised qualitatively in Section Survey Analysis.

Results

Thematic analysis of the one-on-one interview and focus group

Viewing this study within the theoretical framework of "sharing knowledge" proposed by Boyer (1990, 1996) and discussed in the Introduction, three main themes emerged: Motivation to share knowledge, Barriers to sharing knowledge, and Skills for sharing knowledge (Figure 2). The palaeoscientists interviewed all had strong individual commitments to sharing knowledge that were not determined by institutional requirements or a reward system. While this was an inspiring and admirable sentiment, further studies attempting to recruit palaeoscientists for interview or focus groups who are **unenthusiastic** about scicomm would be beneficial for understanding different views on the topic. However, some survey respondents (see Section Survey Analysis) expressed little desire or commitment to engage in scicomm (in their free-text responses), and so fortunately a diversity of views was captured overall by the use of a mixed methods approach. With regard to interview/focus group participants, a clear lack of institutional support emerged as the main barrier to sharing knowledge *via* public outreach as often and widely as they would have liked.

> One participant commented: *"I've been actively discouraged from doing too much outreach, because it seemed to be a deterrent … that's taking time away from my primary role, which is research. When you're really passionate about communicating science, even though it might not be your primary role at that institution, you find different ways to get the word out."*

In order to participate in outreach to a level that they deemed appropriate, participants often experienced conflicts with other academic responsibilities and had time management issues (Figure 2). People felt that science communication would be the first task to be "cut" if time was limited, although all agreed that it remained a responsibility for academics, whether directly stated in work contracts or not.

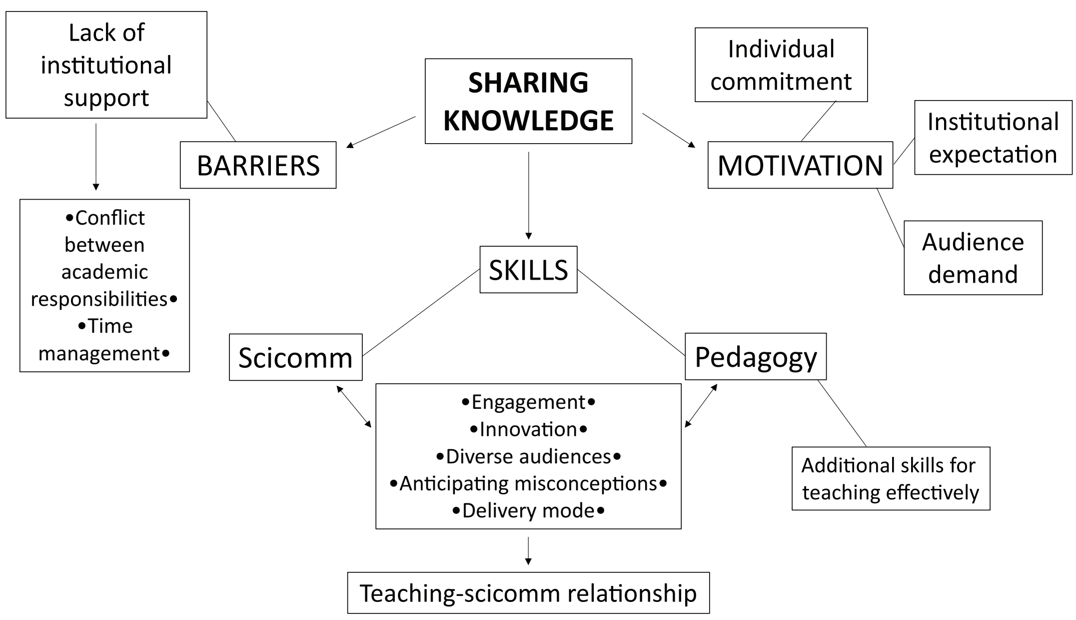

FIGURE 2
Final thematic map of sharing knowledge in the palaeosciences, incorporating the main themes and subthemes emerging from the one-on-one interview and focus group.

> *"Science communication.... is part of our job. The problem is, it's not supported in any way. There's no reward system.*

> *There's a reward system for teaching. There's a reward system for publication. So it's something that [universities] can be a lot better at."*

Despite the lack of an institutional reward structure for outreach at their institutions, participants recounted some experiences where they were still expected by institutions to share their knowledge publicly. A public demand for palaeoscience knowledge was also recognised (Figure 2), and further motivated academics to participate in outreach. Palaeoscientists are conscious of using technology and innovation to achieve this in new ways:

> *"There's never been more opportunities to do a whole bunch of outreach, for example, you can do it through social media, you can do it through decentralised sources like a journal article, popular science articles like National Geographic, ... podcasts, or you can start your own blog articles ... So I think it's really the golden age of science communication, quite frankly."*

When recounting their successes in sharing knowledge, participants also gave detailed descriptions of the specific skills and techniques used to achieve those successes. In the first part of both the one-on-one interview and focus group, questions about pedagogy and scicomm experiences were asked separately. However, participants independently (without prompting) listed five skills as being integral to their success that were later identified as being shared across participants' experiences of both pedagogical and scicomm interactions. These were:

- **Engagement** of the target audience in science.
- Using **innovation and technology** to reach a wider audience.
- Communication of science to more **diverse audiences** by translating it to the correct level.
- **Anticipating misconceptions** of the audience regarding fundamental science concepts.
- Changing the **delivery mode** from a passive to a more active approach.

These shared skills or shared competencies are an excellent match for the crosscutting themes drawn from the literature on general science education and communication, identified in Section Making the Case for the Teaching-Scicomm Relationship. Interestingly, participants were often not consciously aware that they had mentioned needing these skills in both fields. Only in the last part of the interview and focus group were specific questions asked about any possible links between teaching and scicomm. Despite the above shared skills already being mentioned earlier on when participants were asked about pedagogy and scicomm separately, a substantial number of people didn't recount them when quizzed about the teaching-scicomm relationship. Although most agreed with the statement that a better science communicator would automatically be a better teacher, they sometimes couldn't quite elaborate why:

> *"It would be hard to think about situations where you aren't a good communicator, that you are a better teacher, it's like, that doesn't fit..."*

Another participant said:

> *"Yeah, I think that I have to think about it. I'm sorry. I can't give you a short answer right now."*

However, two shared skills were consciously identified as being responsible for both good scicomm and good university teaching: those of engaging the audience, and communicating science at the right level:

> *"Often we confuse the level that students are and pitch in a more complicated manner and one often finds one can actually teach a subject that isn't central to one's research better, because one actually has to think about it and work out and try to understand it yourself, and then learn all the difficulties. Like it's probably learning to pitch at the right level. Possibly it makes you actually do better science talks."*

It was also identified that additional skills for teaching effectively are needed that are not as relevant to success in scicomm:

> *"It's more difficult to answer what makes a good university teacher. To be a good communicator, you have to get the message across, and you have to reach out and engage people. As a university teacher, a lot of things come in ... without being very enthusiastic, or even very, very pedagogic, you can still do a pretty good job as a university teacher. If you're very organized, make things according to plan, follow a course book that was already thought through even if you didn't think it through, you can make a good course without having those extremely good communication skills."*

Other skills, such as good people management and accounting, were also thought to be important in overall teaching success, even if those skills were not used directly for pedagogical purposes:

> *"And so we had a couple of pretty interesting cases of people that were suffering psychosis in some of our classes, and that had some strong impact on the rest of the class, but also the university [admin] was involved. And so you have to become a bit of a psychologist in a way, even if you're not teaching psychology, you have to have an idea of crowd control, you have to have an idea of accounting, making sure that you're not using the funding above and beyond what you've been given. So there's a whole bunch of little skill sets that entails, but they're not in the job description [of teaching]."*

In summary, scientists interviewed for this part of the study share knowledge of palaeoscience-related content in both teaching and popular contexts, but prioritise formally rewarded ways of disseminating their knowledge. However, all agreed that other ways of sharing knowledge should be rewarded and supported on an institutional level. They partially recognise the potential for shared competencies in teaching and scicomm, and this could be further exploited to demonstrate the value of including scicomm in the reward system of teaching and research at most institutions.

Survey analysis

Although the low survey response rate (5%) indicates a strong likelihood of a biassed sample of the population, sample answers gathered do represent a broad range of career stages, career types and a reasonable gender balance (Figure 3). Males at senior-career level are overrepresented in the survey, as they are in the field of palaeosciences itself. PhD candidates and postdoctoral fellows are underrepresented in the survey (Figure 3B) compared to the field as a whole, possibly because they had not yet achieved sufficient teaching to meet the survey requirements and thus did not complete it. Although specific questions on country of origin and workplace country were not asked due to a desire to keep the survey as short as possible, it is hoped that a diversity of cultural backgrounds was captured, as palaeoscientists working in at least five major geographical regions (Africa, Asia, Australia, Europe, North America) received the survey. A possible limitation to this is that the survey was only sent out in English, however a large proportion of palaeoscientists, regardless of native language, are also expected to have a working command of English in order to publish in English-language journals. Finally, as with all surveys, it is likely that the answers reflect a bias towards people already interested in the survey subjects (i.e., scicomm and teaching) and that the answers are thus skewed towards answers indicating that both areas are important.

Based on survey answers, mid-career scientists spend by far the most time on teaching (41% of this group spend more half their time teaching; Figure 4A), and also do a fair amount of scicomm (almost two-thirds do between 2 and 10 events per year; Figure 4B). Early- and senior-career scientists spend the most time on scicomm, with 86 and 83% doing more than 2 events per year, respectively (Figure 4B). Retired scientists and those who did not fit the descriptions of the career stages (the "Other" category) also engaged in a lot of scicomm (66%; Figure 4B). Overall, palaeoscientists who answered the questionnaire tend to participate in a total of 2–5 scicomm events per year (Figure 4B), defined as things like public lectures, media interviews, press releases, popular science articles, blogs, social media outreach, or visiting primary / secondary schools.

All survey respondents agreed that a palaeoscientist with good scicomm skills would be a better university teacher (as opposed to a palaeoscientist less proficient at scicomm) in at least some cases (Figure 5A). Future objective studies designed to test whether this is actually true (through student surveys or comparison of class grades) would be ideal, but challenging to implement. When asked a follow-up question to explain their answer, the majority of answers (mentioned by 40% of respondents; Figure 5B) listed improved communication as the reason for their agreement (Figure 5B). Other reasons given less frequently (3–12% of answers) were knowing how to engage people in science, the ability to translate or "pitch" science at different levels, and passion for the subject (Figure 5B). Overall, respondents were supportive of the idea that good scicomm skills benefit teaching in their free-text responses. Some of the replies included the following statements:

> *"If you cannot clearly communicate, you cannot effectively teach."*
>
> *"If you are a good science communicator it is because you can put things in a context of why someone should care. This translates to the classroom..."*
>
> *"A bored or disengaged student does not learn."*
>
> *"The ability to break complicated science into manageable, understandable pieces is a skill that most science communicators have."*

Despite all respondents believing that good scicomm skills benefited teaching in some way, almost a third of palaeoscientists (29%) also felt that additional skills (not related to scicomm) were needed to succeed as a teacher (categorised under "Different skills needed" in Figure 5B). However, in the same breath, they also shared the perception that being a science communicator was comparatively much simpler than teaching, and the only skill really needed to succeed at scicomm was good communication. For example:

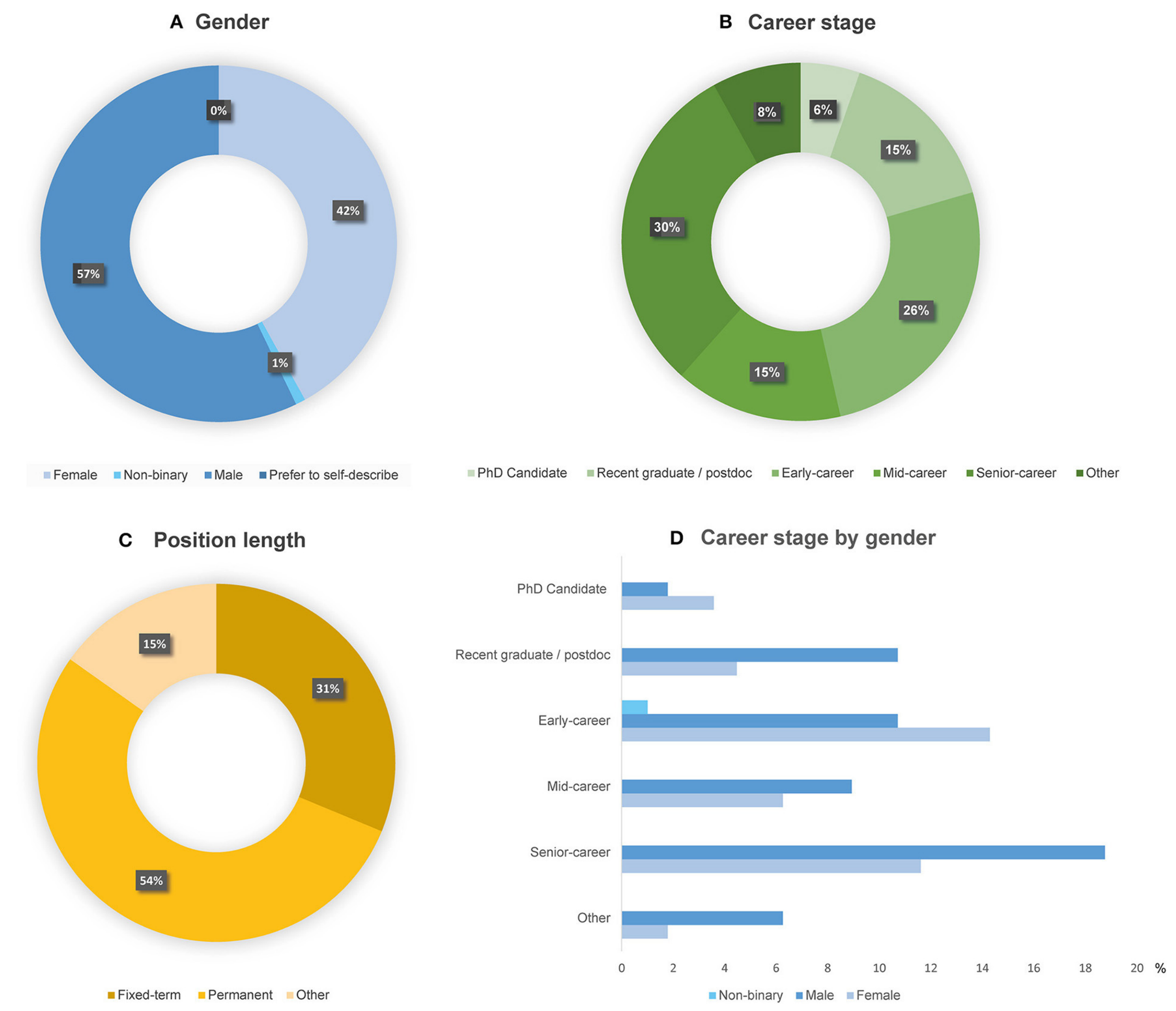

FIGURE 3
Socio-demographic variables of survey respondents; **(A)** Gender, **(B)** Career stage, **(C)** Position type, **(D)** Career stage by gender.

> *"**Being an educator is about more than simple communication**. You have to be able to form and nurture an ongoing relationship with students, be able to develop fair and unbiased assessments, interesting and appropriate activities for the class, and be able to construct and manage your class time to benefit a wide variety of student backgrounds and knowledge bases. This is all going to depend on the education, experience, and personality of the person in question."*

Another aspect the survey uncovered was the relatively narrow view of "outreach and science communication" held by most respondents. The overwhelming majority saw this merely as "speaking to children or the general public, who are considered to have a simplistic knowledge of science" (gathered from free-text responses). This was despite specifying a broad definition of scicomm in the survey, with examples ranging from a public lecture, media interview, visiting primary or secondary schools to a press release, popular science article, blog, or social media outreach.

When asked about the reverse, i.e., whether being a good teacher automatically translated into being a better communicator [than someone who was not a good teacher], respondents perceived the situation in quite a dissimilar way (Figure 6). Over two-thirds of respondents (67%)

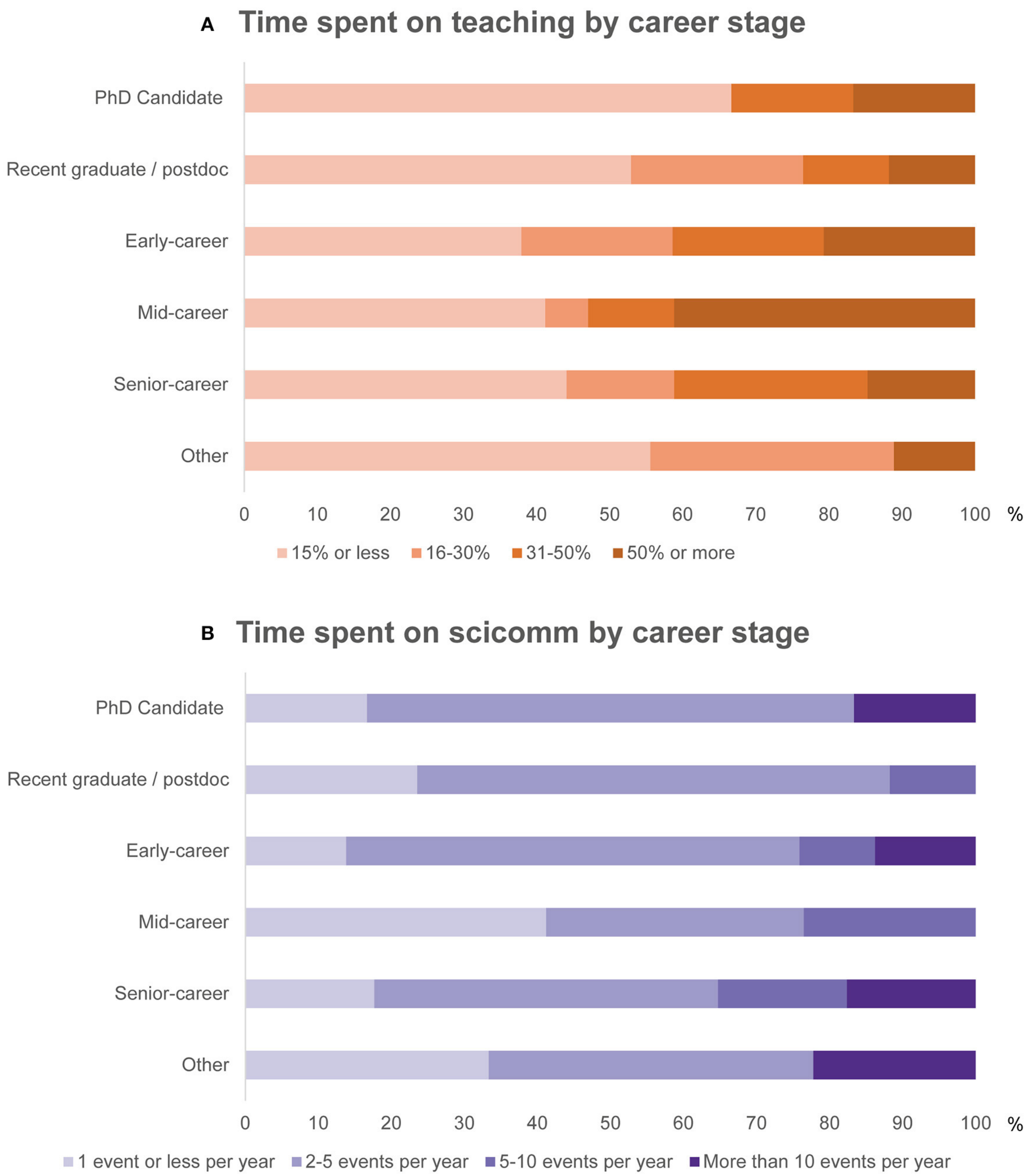

FIGURE 4
How does a palaeoscientist's career stage correlate with time spent on **(A)** teaching and **(B)** scicomm?

thought that different skills were needed for each role; when a shared skill was mentioned as crossing over from teaching to scicomm, it was almost always improved communication (Figure 6B), as in Figure 5B. A sizeable minority (10%) now argued that in few to no cases was a good teacher a better science communicator [than if they were not a good teacher] (Figure 6A), unlike the previous question where all respondents agreed that a palaeoscientist with good scicomm skills would be a better teacher.

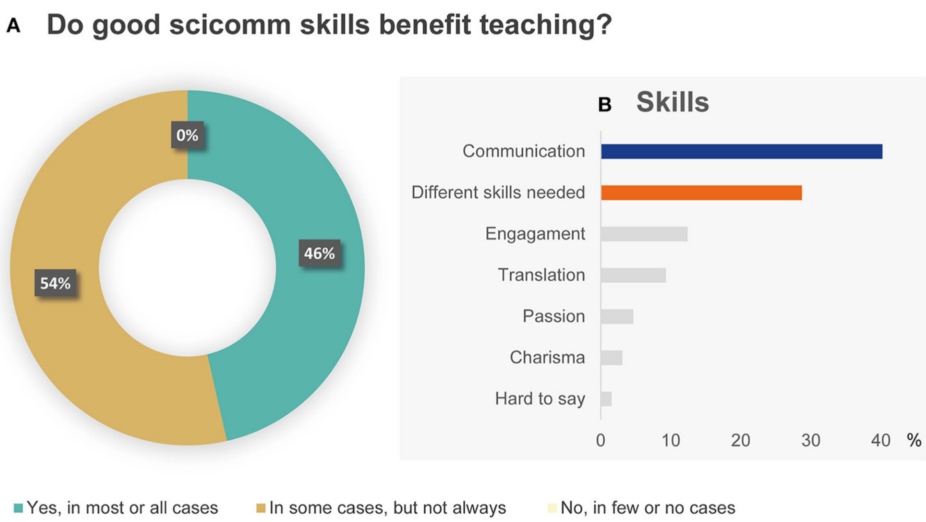

FIGURE 5
How do scicomm skills benefit teaching in the palaeosciences? Respondents could choose between three multiple-choice options (indicated in mustard, green, and beige) for part **(A)**, but could list multiple skills in free text for part **(B)**.

Perceptions of what makes a good university teacher also revealed a lack of pedagogical knowledge and/or training among some respondents. For example:

> "***Some good university teachers*** *are not good at re-calibrating their material to a general audience, talk at too high a level or engage in rote explanation without a lot of engagement activities.*"
>
> "***Some people are great teachers****, but they struggle. . . when they are forced to 'lower the academic level' or use non-technical language for better communicating ideas.*"
>
> "***A good teacher*** *may simply regurgitate facts and be highly organized, with little excitement or flare to entice...*"

If the afore-mentioned teachers are unable to engage and motivate their audience, translate their material to the correct level, or explain jargon, all key aspects for successful teaching (see Table 1 for references), could they really be great or even good teachers? It would have been interesting to know whether the respondents who held these views have ever received pedagogical training.

The survey reveals that palaeoscientists face almost exactly the same major obstacles in both their teaching and outreach activities (Table 2). The building of formal support/reward systems and funding mechanisms *via* institutions is critical to address the obstacles at the top of Table 2 (shown in regular font). On the other hand, training on the individual level is needed to address the obstacles in the lower part of Table 2 (in italics), but this should probably also be driven by institutions. Such professional development courses would benefit both employees and their organisations (Rodari and Weitkamp, 2015), but individuals with permanent positions (comprising more than half of respondents in this survey) may not be motivated to invest time in further training unless it would bring tangible benefits to their career.

The shared competencies for success in both teaching and scicomm identified in Section Thematic Analysis of the One-on-One Interview and Focus Group are highly applicable to tackling the obstacles in italics (Table 2), at least in part. Formal training should focus on engaging target audiences, using innovation and technology effectively, anticipating misconceptions, translating science to the correct level, and changing the delivery mode from a passive to a more active approach. By drawing on both the scholarship of teaching and scicomm best practises, a more diverse approach to sharing knowledge in the palaeosciences could be developed.

Discussion

Although they have different audiences, university-level pedagogy and public science communication both have the same overarching goal: to facilitate the sharing of knowledge and understanding from a specialist or expert, to a non-specialist group (Boyer, 1996; McKinnon and Vos, 2015). This study has uncovered that that palaeoscience educators hold a variety of views with regards to sharing knowledge across teaching and scicomm.

A finding echoed by previous research (Peters et al., 2008; Casini and Neresini, 2013; Besley et al., 2018; Loroño-Leturiondo and Davies, 2018) is that most palaeoscientists

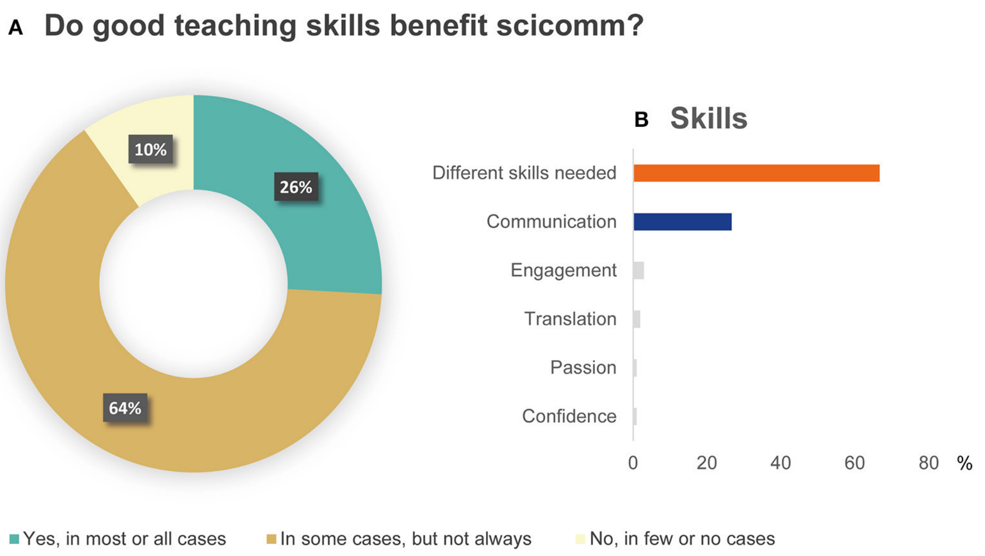

FIGURE 6
How do teaching skills benefit scicomm in the palaeosciences? Respondents could choose between three multiple-choice options (indicated in mustard, green, and beige) for part **(A)**, but could list multiple skills in free text for part **(B)**.

TABLE 2 Survey respondents' views of the biggest obstacles faced in palaeoscience-related teaching and outreach (respondents could list multiple obstacles).

In teaching palaeo-related content %	Biggest obstacles faced	In palaeo-scicomm & outreach %	Possible solutions
3	Conflict between academic responsibilities	7	- Formalised institutional reward system for scicomm, as with research and teaching
28	General lack of institutional/governmental support	14	
13	Inappropriate fossil collections/no field sites for teaching	4	- More appropriate funding allocated and institutional mechanisms built for sharing knowledge in different contexts
14	Time management	19	
1	Lack of connexion with community	7	
0	Lack of tangible benefits	2	
3	None	7	
0	*Personal lack of confidence or training*	1	
3	*Not making use of innovation & technology*	1	- Individual training for all palaeoscientists (facilitated by institutions at student or professional level) on diverse ways to share knowledge, comprising pedagogical, and scicomm best practises
7	*Preconceived incorrect notions*	17	
21	*Problems engaging students/media/audience*	16	
7	*Problems translating complex ideas*	8	

The right-hand column indicates possible solutions to these obstacles, which can be accomplished via two routes: obstacles for institutions to address (shown in regular font), and obstacles that can be addressed by training on the individual level (shown in italics). However, individual training should probably also be promoted and structured by institutions, in the interests of inclusion and uplifting the field as a whole.

who participated in this study believed they had a personal responsibility to share their scientific knowledge, and made regular efforts to do it. Major obstacles to sharing their knowledge included institutional lack of support, time constraints, and conflicts with other academic responsibilities. This could pose a particular challenge for scientists at the start of their careers (within 10 years of the PhD degree being awarded), as these groups tend to spend the most time on scicomm (Figure 4B) but also have immense pressure to establish themselves by publishing extensively (Müller, 2014).

While some palaeoscientists surveyed believe that the fields of teaching and scicomm have little or nothing to learn from each other, they are in the minority. However, the broad agreement that scicomm can benefit pedagogy boils down mainly to "improved communication." This reveals a rather simplistic view of scicomm and ignores the diversity of skills that are required to be successful at it (Sevian and Gonsalves, 2008; Kapon et al., 2009; Somerville and Hassol, 2011; Longnecker and Gondwe, 2014). Importantly, most respondents did not realise that other scicomm skills (e.g., engagement, translation of science to the correct level, passion, charisma; Figure 5B) are transferrable to the university classroom. This suggests the potential exists for a mutually beneficial relationship between teaching and scicomm in the palaeosciences community, but is not being exploited to its full extent at present.

Furthermore, despite listing a number of obstacles to achieving success in teaching and scicomm, palaeoscientists seem to have yet to recognise that formal skills training could help to alleviate these challenges. Ironically, only one respondent (out of 112) identified that lack of personal training was an obstacle to their success in scicomm (Table 2). Not one person said that lack of training contributed to their problems in teaching. This may be attributable to a lack of awareness on existing pedagogical/scicomm skills training, but is probably more likely to be driven by the widely reported phenomenon of self-serving bias, where people tend to take credit for their successes but blame external factors for their failures (Shepperd et al., 2008). Self-serving bias has been demonstrated in the classroom setting for both teachers and students (McAllister, 1996), and shown to become more common when people observe others also shifting blame for their own personal failings (the “blame contagion” hypothesis of Fast and Tiedens, 2010). Thus, this tendency can quickly become embedded in the shared culture of organisations such as universities, which is detrimental because the habit of blame damages both individual and collective wellbeing, as well as overall performance (Fast and Tiedens, 2010).

It is clear from this and many other studies that current training to become a scientist, or to perform outreach, does not meet complex societal needs for effective science communication and policy engagement (Leshner, 2003, 2007; Besley and Tanner, 2011; Rodari and Weitkamp, 2015; Mercer-Mapstone and Kuchel, 2017; Paasche and Åkesson, 2019; Dudo et al., 2021—but with notable exceptions; see e.g., Longnecker, 2014) and more scientists are arguing for greater emphasis on communicating scientific results to the public, media, and policymakers (Figueres et al., 2017; Knudsen and de Bolsée, 2019). This indicates a real need for institutions to invest in increased scicomm training in the palaeosciences, particularly considering the urgency of sharing palaeoscientific information with diverse audiences in the context of current and future climate change (Besley and Dudo, 2017; Knudsen and de Bolsée, 2019).

A number of shared competencies between teaching and scicomm were identified in this study that should be prioritised in any future training offered to palaeoscientists. Besides general skills such as using technology and innovation for improved communication, there are also shared competencies that have specific application to the palaeosciences. Physically taking an “audience” into an excavation site or letting them handle fossils in the laboratory allows for engagement in science on a tangible level that is perhaps not possible in more theoretical STEM subjects. Anticipating misconceptions is another shared competency that is particularly important for successfully sharing knowledge on the controversial topics of evolution and climate change. “Experts” can also have misconceptions and learn from those with local knowledge (e.g., Manyweathers et al., 2020), and this is more likely to happen in informal settings such as community-based scicomm or fieldwork than in a formalised university classroom. The possibility thus exists for palaeoscientists to embrace, rather than decry, these challenges, by realising they can offer a unique scicomm perspective within STEM.

For this to succeed, it needs to occur in conjunction with inviting dialogue on such topics, and finding ways to actively engage audiences in the knowledge-sharing process. Just as active learning approaches are superior to passive learning in terms of student performance, the ineffective diffusionist model in scicomm, which assumes the public are simply lacking the correct information, needs to shift towards an active dialogue that also takes into account the diversity of public values, goals, beliefs and contexts (Bucchi, 2008; Besley and Tanner, 2011; Longnecker and Gondwe, 2014; Cortassa, 2016; Longnecker, 2016, 2022; National Academies of Sciences Medicine, 2017; Illingworth et al., 2018).

Open science is now a policy priority for the European Commission, and encourages researchers to share knowledge and data with all relevant stakeholders, as early as possible in the research process (Cheng and Shunke, 2008). However, “open” science is meaningless if target audiences cannot understand it. Sharing knowledge by using a continuum of scientific understanding advocates the transmission of knowledge to different target audiences, whilst acknowledging that individuals, no matter their level of scientific understanding, have the right to access different kinds of knowledge (Cloître and Shinn, 1985; Bucchi, 2008). Approaches to sharing this knowledge also need to go beyond a one-way delivery of information after the fact, for example integrating indigenous people and cultural values into the research process itself (Fleming et al., 2020; Wilkinson et al., 2020).

Using a variety of communication styles and contexts within the holistic framework of sharing knowledge, can help to make this knowledge truly accessible and open (Boyer, 1996). It could potentially improve both student and teacher attitudes to science, stimulate the engagement of young students, contribute to more clearly written research proposals and journal publications, and develop better science skills and knowledge at tertiary level, as well as broader perspectives on science and diversity within the general population (Stiller-Reeve et al., 2016). Additionally, participation in outreach can help to shape research questions for scientists that bring academia, society, and policy into closer alignment (Leshner, 2007; Brownell et al., 2013; Rauser et al., 2017; Nisbet, 2018). These benefits must be recognised at both the individual and institutional levels to motivate real change in the dissemination of science, which never been more important in our "post-factual society." As summed up by one of the survey respondents: "*You can know a lot, but if you can't communicate it, what is the real value of that knowledge?*"

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

NB conceived the study, designed the questionnaire, performed interviews, collected, organised, analysed data, wrote the first draft of the manuscript, and made revisions to the final draft.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor AB declared a shared affiliation with the author at the time of review.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.852122/full#supplementary-material

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