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Creative pedagogies in digital STEAM practices: natural, technological and cultural entanglements for powerful learning and activism

Kerry Chappell[1] · **Lindsay Hetherington**[1]

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Abstract
This paper delves deeply into the creative pedagogies which support cutting edge digital STEAM practice across primary and secondary school settings. It contextualises the research within current STEAM agendas including transdisciplinarity, and STEAM and technology and goes on to offer insight from the novel context of ocean learning to develop and extend a theorisation of creative pedagogies as entwining both creative teaching and teaching for creativity as embodied, democratic, dialogic and material processes. Intra-action between theory, praxis, nature, culture, the digital and humans enables an emergent perspective about changing the dynamics of power to develop ocean or environmental learning and related activism. Derived from research into an ocean education project, which aimed to develop students' ocean literacy through the combined educative principles of creative pedagogies and digital technologies (Augmented and Virtual Realities), the research draws on data from six projects across primary and secondary school settings in Denmark, Spain and England. It used a 'diffractive' analytic technique, inspired by new materialist theory, to explore the messy mixtures of natural, cultural and technological environments that were being learned through. This involved the development of four material-dialogic assemblages each including diffractive switches. Each is presented first through a 'piece' which demonstrates each assemblage's connection to the core question, followed by 'ripples', which briefly articulate the new learning and questions arising from that assemblage. The four assemblages cover the irresistibility of making kin, the relationships between lively bodies and virtual environments, the importance of spacetimematter in environmental edu-activism and trajectories between transience, stability and dialogic space. The paper leaves the reader/engager with a selection of prompts to highlight the research's contribution to current STEAM agendas related to changing power dynamics, and to provoke reader/engagers' own practices. These can include new pedagogies and activisms, as well as theoretical developments to the combined educative principles of creative pedagogies and digital technologies within STEAM education.

Keywords STEAM · Creative pedagogies · Digital pedagogies · Ocean literacy · Postqualitative

✉ Kerry Chappell
K.A.Chappell@exeter.ac.uk

[1] School of Education, St Luke's Campus, University of Exeter, Exeter EX1 2LU, UK

This paper delves deeply into the creative pedagogies which support cutting edge digital STEAM practice across European primary and secondary school settings. It begins by contextualising the research within current STEAM agendas including transdisciplinarity, and STEAM and technology. It goes on to offer insight from the novel context of ocean learning to develop and extend a theorisation of creative pedagogies as entwining both creative teaching and teaching for creativity as embodied, democratic, dialogic and material processes. Intra-action between theory, praxis, nature, culture, the digital and humans enable an emergent perspective about changing the dynamics of power to develop ocean or environmental learning and related activism.

STEAM education context

In order to research and develop creative pedagogies in this way, we need to understand the STEAM (Science, Technology, Engineering, Arts and Maths) context within which they are situated. STEAM education has been developing as an area of European practice for well over 10 years, but both the STEM (Science, Technology, Engineering and Maths) and STEAM acronyms exist with a variety of definitions and manifestations in practice (Colucci-Gray, Burnard, Cooke, Davies, Gray, and Trowsdale 2017). This aside, Laura Colucci-Gray, Burnard, Cooke, Davies, Gray, and Trowsdale (2017) argue that STEM can be seen as both an identification of economically potent and therefore powerful disciplines, and an educational policy construct. In relation to the latter it can be implied that STEM subjects are integrated, that they address real-world problems, and better connect to communities. However, STEM has equally been criticised for siloing science disciplines together (DBIS 2014), creating an impenetrable suite of difficult disciplines, and countering creativity (Yakman 2010), which can be viewed as a key vehicle for empowerment, identity development and agency (Banaji, Burn, and Buckingham 2010).

Partially in response to these criticisms and spurred by arguments from the likes of the NextGen report (2011), the STEAM agenda grew around this time, arguing that the Arts should be at the heart of education to facilitate innovation and the accompanying economic advantages (DCMS 2013). STEAM practices are becoming more sophisticated across Europe, and increasingly experienced networks of practitioners and academics are interrogating their nuances, including in relation to climate change (Rudd 2021) and in large-scale arts/science education initiatives (Conradty and Bogner 2019). Others have considered cultural dynamics such as gender (Goldschmidt and Bogner 2016), as well as how the role of politically driven government support can influence implementation in different cultural contexts, for example in Japan (Matsuura and Nakamura 2021) and Uzbekistan (Lee 2021). Within this, our research endeavours to build on developing understanding of creative pedagogies use within European (Chappell, Hetherington, Ruck Keene, Wren, Alexopoulos, Ben-Horin, Nikolopoulos, Robberstad, Sotiriou, and Bogner 2019) and wider international research (Harris and de Bruin 2018), which is intended to facilitate the creativity, and potential agentic shifts of which STEAM is capable (Yakman 2010). Our approach is supported by the work of colleagues such as Upadhyay, Coffino, Alberts, and Rummel (2021) who demonstrate how STEAM practices can have positive influences on students' critical consciousness and social awareness. Our research then aims to build on Choi, Won, Chu, Cha, Shin, and Kim (2021) and Won, Choi, Chu, Cha, Shin and Kim (2021) research which, respectively, show how STEAM education can develop students' climate change literacy and how teachers' pedagogy can contribute to this. In turn, we aim to contribute

to helping students to increase their social engagement and to begin to understand how to solve real-world 'wicked' problems (Kolko 2012), positioned through a posthuman lens.

Disciplinary interaction within STEAM education

In positioning the research in this paper within STEAM, it is also important to situate it in relation to understandings of how disciplines interact in education, as there are many different ways in which disciplines can interact within STEAM. Dan Harris and Leon de Bruin (2018) have demonstrated that international secondary STEAM education can be understood in terms of inter-, trans- and cross-disciplinary learning which is shaped by dialogue and teacher collaboration. In our work, STEAM is understood in similar ways, where possible with the emphasis on transdisciplinarity, articulated using Solomon Benatar's (2000, p. 171) definition: "an integrated approach to complex problems using the methodology and insights from a range of disciplines with differing perspectives on the problem under consideration". Our research acknowledges that on occasion multi- and interdisciplinary subject entanglements occur within STEAM, but that transdisciplinarity is the most desired, as relationships transcend individual disciplines, and there is therefore the greatest potential to solve complex problems which challenge disciplinary boundaries. This approach also aims to overcome the kinds of power imbalances that Colucci-Gray, Burnard, Cooke, Davies, Gray and Trowsdale (2017) highlight in their identification of STEM subjects as economically potent, compared to the arts disciplines with which they interact within STEAM practices. Richard Davies and Jo Trowsdale (2021) are helpful here as they demonstrate that whilst schools often welcome the arts, they are given little actual curriculum time and positioned in a 'servant' role. They articulate how this position can be challenged and a more even power balance be encouraged through the idea of shared curricular space and altering schools to support a multicultural frame.

Our research remains alert to these disciplinary power relationships and their impacts within STEAM, as well as the cultural imbalances which in European school science curricula often retain an emphasis on the role of individual white, male scientists and a 'lack of attention to [the science curriculum's] intrinsic social, political and cultural aspects' (Rezende and Ostermann 2020). We have found de Sousa Santos (2018) useful in attending to such cultural and power imbalances between and within STEAM disciplines. For example, the concept of 'epistemic justice' (aims for equality of treatment of all forms of knowledge and knowers by bringing different knowledges into dialogue to understand how knowledge is generated). We find this idea helpful in recognising the cultural nature of disciplinary knowledge and school practices in our ongoing work, acknowledging power imbalances as sources of contraction and tension in need of ongoing attention within both practice and research.

The role of technology in STEAM education

In working to understand creative pedagogies which support STEAM, our research is also positioned within the recent turn towards more fully incorporating technology into STEAM educational practices through the use of increasingly sophisticated digital interventions. As Hong Lin (2015) argues, within STEAM education, there is a need to inclusively equip all young people with the complex digital skills required for dealing with rapid change. This

increasingly includes the use of mobile devices (Grant 2015), digital data analytics tools (Wellington, Easton, Davis and Yeh 2020), distance-learning educational software (Manousou and Lionarakis 2013), in virtual learning environments (Walsh, Chappell and Craft 2017), game-based learning (Breien and Wasson 2022) and immersive technologies such as Augmented Reality in STEAM education (Jesionkowska, Wild and Deval 2020), Augmented Reality in marine education (Lu and Lui 2015); Augmented Reality using Trace Readers (Kyza and Georgiou 2019), and in Virtual Reality (Wrzesien and Alcañiz Raya 2010). As the latter acknowledges, research needs to attend to the teacher support and student upskilling that needs to occur for this digitisation of STEAM creative pedagogies to be successful. It is also necessary to attend to the associated resourcing and costs of such devices, software and online environments, which can lead to unequal access for socio-economically disadvantaged schools and their students, as was particularly highlighted during the Covid-19 pandemic even with respect to basic access to technology (Montacute 2020).

Posthuman creativity and creative pedagogies in STEAM education

Within our research into digital STEAM practices, creative pedagogies are defined as entwining both creative teaching and teaching for creativity (Jeffrey and Craft 2004), with Kerry Chappell (2018), Chappell, Hetherington, Ruck Keene, Wren, Alexopoulos, Ben-Horin, Nikolopoulos, Robberstad, Sotiriou, and Bogner (2019) and Hetherington, Chappell, Ruck Keene, and Wren (2019) all conceptualising these processes as embodied, democratic, dialogic and material. This aims to provide an active alternative to more dominant, psychological creativity conceptualisations (e.g. Vincent-Lancrin, González-Sancho, Bouckaert, de Luca, Fernández-Barrerra, Jacotin, Urgel, and Vidal 2019) by positioning embodied material dialogues as the driver for the creation of new knowledge (rather than individual cognitive skills). Dialogues can occur between people, and multiple others (Bakhtin and Holdqvist 1981), including ideas, texts, objects, elements of the environment and technologies. Importantly, a dialogue is not a purely human negotiation towards similar points of view, but a cyclical questioning which generates answers which generate further questions. By including other-than–humans in this process, our research characterises creativity within the posthuman turn (e.g. Braidotti 2013), which decentres the human and allows for influential phenomena and subjectivities to emerge from intra-actions between multiple agents (Barad 2007). One result of this, in line with Kayumova, McGuire and Cardello (2019) is to more closely enmesh nature and culture in the creative process within environmentally focused science education, rather than to polarise them. This has the creative potential to counter environmental injustice by considering impacts on other-than-humans as well as humans. Harris and Stacey Holman-Jones (2022) argue that this turn is vital to break the impasse that now exists with humans (particularly the Western, capitalist, neoliberal kind) alone, unable to solve the wicked problems of the Anthropocene that they have generated. By taking a posthumanising approach to creativity, a growing collective of academics and practitioners including Carol Taylor and Annouchka Bayley (2019), Jasmine Ulmer (2017), Chappell (2021) and Hetherington, Chappell, Ruck Keene, and Wren (2019) are seeking alternative practices which have the potential for impact on issues such as climate change, educational inequality and digital subversion through developing learning and related activism.

Stemming from this conceptualisation of creativity, Kerry Chappell has led on the development of a set of eight creative pedagogies which have been designed through

rigorous evaluative research to facilitate creativity. Heather Wren, Chappell and Hetherington (2022) provide a full overview of these pedagogies and how they were developed through mixed methods research. These were used to support project development in this research. In summary, and closely connected to the grounding in dialogue and transdisciplinarity above, they are as follows: *Dialogue*—pedagogically asking questions in a way which leads to new ideas and then more questions; *Transdisciplinarity*—defined by the relationship between disciplines serving the question or problem in hand; *Individual, collaborative and communal activities for change*—ensuring emphasis on individual contributions alongside collaboration within communally driven exploratory and experimental learning often with an emphasis on activism; *Balance and navigation*—working to balance control and freedom, structure and openness, and power relationships, whilst acknowledging educational tensions of assessment, marketisation, and time; *Empowerment and agency*—Giving participants ownership of the learning through socially engaged practices, to ask their own questions and make their own mistakes; *Risk, Immersion and play*—grounding learning in risky questions, encouraging immersion in problems and for playful approaches; *Possibilities*—allowing for multiple possibilities both in terms of thinking and spaces; *Ethics and Trusteeship*—considering the ethical implications and impacts on those around them of their creativity, and taking responsibility for holding the values.

The complementary posthuman turn within cultural studies of STEAM education

Whilst our work is positioned within the creativity in education posthuman turn, we also align ourselves with the posthuman turn within cultural studies of STEAM, environmental and wider science education, exemplified in the work of Jeong, Sherman and Tippins (2021), Kayumova, McGuire and Cardello (2019), Yew-Jin Lee (2008), Blanche Verlie (2020), and Jennifer McRuer and Margarita Zethelius (2017). Our work especially connects to Jeong, Sherman and Tippins (2021) arguments for taking a posthuman approach to studying the ocean as part of sustainability and environmental education. Jeong et al. make key arguments for posthuman perspectives providing viable alternatives to Western, humanist approaches to science education for sustainability, acknowledging life in all its forms, from micro to macro and focusing on humans' relationships with cultural and natural ecologies. They foreground intra-activity, as a means for learners to move beyond human-dominated ecological sustainability to understand human beings' entanglement with the world through interrogating the relationships between culture and nature. Whilst their work forefronts science education per se, our work shines a similar spotlight on science integrated with technology, arts and maths within STEAM initiatives, and endeavours to show what this means as part of a journey towards sustainability in terms of educational practice and research.

Developing ocean literacy in European schools

So, in 'delving deeply' into the creative pedagogies which support cutting edge digital STEAM practice, we carried out research within an education project which aimed to develop students' ocean literacy through the combined educative principles of creative pedagogies (see eight features detailed above) and digital technologies (Augmented and

Virtual Realities). The integration of these two strands of work to support the teaching of ocean literacy is based on the need to find ways of engaging pupils intellectually and socially with the size, scale and complexity of the ocean, and an ethical, activist stance aiming to result in developing pupils' responsibility for and with the environment. In combination the project was working with the following principles:

1. The ocean literacy learning sequence focuses on a set of principles (NOAA 2020), as appropriate for pupils' age and prior learning;
2. Pedagogy aims to bridge disciplinary boundaries by enabling pupils to use knowledge, ideas and processes from different disciplines in order to ask and answer their own questions;
3. Teaching and learning draws on eight creative pedagogies features (Chappell, Hetherington, Ruck-Keene, Slade, and Cukurova 2016; Wren et al., in review), such as playful and immersive experiences, to connect pupils with the ocean both intellectually and affectively. They will promote embodied and material-dialogic interaction with the ocean, nature and technology, and aim to empower pupils to work individually and collaboratively;
4. Digital technologies should be used to support model-based inquiry and data-driven learning;
5. Virtual and/or augmented reality technologies are used to support pupil learning, enabling them to visualise otherwise difficult to access phenomena and processes, including systems approaches to critical oceans concepts;
6. Technologies are used to support communication with external stakeholders such as scientists and the public, enabling pupils to learn about the ocean within a wider community context linked to the creative pedagogy feature individual, collaborative and communal action for change.

In so doing we focused on six projects, all in Europe, two each in Denmark, Spain and England with pupils aged 7–11 years (Upper Primary) and 11–14 years (Lower Secondary), described in Table 1. Participating schools were all located in coastal towns or cities, with varying structures, curricula, size, intake and socio-economic catchment area. The Spanish school is a combined, plurilingual primary and secondary school located in a city in Northern Spain, which has a strong and ongoing connection to research and curriculum innovation with respect to the use of digital technologies in learning. Located in a thriving port city, the school is in a relatively affluent area. The Danish schools were initially separate primary and secondary schools undergoing a restructuring that was bringing them together under a centralised management. Children learn English in both primary and secondary, though largely learn in Danish. The schools are located in a small coastal city where tourism and a commercial port are key economic drivers. The English school participating in the projects was a primary school in a coastal port city with a naval history that continues to provide a substantial percentage of employment in the city. The school is located in a socio-economically deprived part of the city, meaning that some pupils had had limited prior access to the Ocean despite its proximity to their homes.

In line with our posthumanist framing above, the research reported in this paper took on a postqualitative analytical approach (e.g. St Pierre 2021). This is explained in the next section along with insight into the emergence of our focus question: What messy mixtures of natural, cultural and technological environments were learned through?

Table 1 Description of the six projects

Title	Country	Age group	Description
Biodiversity	DK	14–15	Pupils explore biodiversity using a 5E model in a interdisciplinary way, drawing on VR and creative approaches using the Arts to communicate their learning
Nursing grounds for fish	DK	10–11	Pupils create and deploy nursing grounds for fish, designing and building them, and tracking them using 360 cameras and exploration in VR
Ocean Adaptations	UK	9–10	Pupils learn in response to their own questions about how organisms are adapted to survive in the ocean, based on interdisciplinary stimulus. The VR space maintains connection with the aquarium stimulus and the ocean experts from the aquarium
Plastic Pollution	UK	9–10	Pupils learn about the problem of ocean plastics using transdisciplinary creative pedagogies and digital technologies, whilst developing the potential for activism
Accessing the ocean	ES	11–14	Pupils learn some key ideas in ocean literacy through an aquarium visit and broader research, then draw on creative approaches within VR and AR spaces to communicate their ideas
Shoal of Fish	ES	7–11	Pupils learn about the ocean and fish behaviour, drawing on their own questions and reflective conversations and dialogue. They create a game using AR

Our diffractive analytical approach

'Messiness' is recognised within posthuman onto-epistemological research frameworks as a productive, generative place, space and process (Brisini and Simmons 2016), emanating from materiality (Broderick and Gleason 2016) and often related to notions of care (Defalco 2020). Within postqualitative inquiry, researchers commonly acknowledge its messiness both ontologically and epistemologically. As Elizabeth St Pierre argues, with roots in posthuman, poststructural and postmodern thought, postqualitative inquiry is not about following a particular recipe or instruction in order to achieve rigour (St Pierre 2013), but is "*immanent*…It never exists, it never is. It must be invented, created differently each time" (St Pierre 2021, p. 6). In this spirit, we have worked with Chappell's (2021) meshing of Ulmer's (2017) suggestion to practice equivalence and experimentation, Taylor's (2017) call to recast new ways of knowing and researching, Karen Barad's (2007) request to do ethics differently through respons-ability whilst remaining alert to Donna Haraway's (2008) reminder to trouble our thinking and doing with curious care. The project within our research is, at its heart, relational, exploring the learning that takes place within living dialogic spaces where disciplines, pedagogies, nature, people and 'things' (artefacts, the digital, living organisms) intra-act, making diffractive inquiry appropriate to offer space for experimentation, recasting, respons-ability and care. To this end our research outcomes in response to our question include foci on all these elements, not simply learners' learning; sometimes teacher and researcher progression might emerge and at other times the other-than-human is centralised. Key to this way of thinking is the idea that diffraction is a metaphor for analysis that aims to spread into new spaces like the scattering of light passing through a slit or the ripples on water, contrasting with reflection as a metaphor for looking at an object reflecting back. The new thinking arising from a diffractive analysis is therefore unpredictable, with it possible for the learning of all humans and other-than-humans to come to the fore.

Despite the resistance to prescribed methodology that lies at the heart of the notion of postqualitative inquiry, our work does draw on 'data', collected using 'methods' as part of the wider project within which this postqualitative exploration is situated. In the design of the overall research project, in which more standard research approaches such as interviewing, capturing photographs of student work, and questionnaires were included in order to respond to some specific research questions, we created opportunities to de-centre the human and focus on the material dialogues within the projects. The postqualitative inquiry described in this paper draws on some of this 'data' but focuses on a distinctive, postqualitative approach to analysis that is responsive, inventive, creative and experimental as outlined above. We have approached this using diffractive inquiry (see e.g. Mazzei, 2014), which has a hallmark of cutting theory, methods, data, the object/s-of-study and the researchers 'together-apart', to interrupt and dissect the object of study in coproductive ways to materialise new meanings (Barad 2014). This process of methodological, agential cuts (Barad 2007) does not proceed through a predefined series of steps that are performed in the same way in every study: Rather, our analysis is in a posthuman mode of theory-driven thinking and writing rather than a particular approach to the analysis of data (see e.g. Aghasaleh and St Pierre 2014). We do not, therefore, seek to measure the strength of our analysis through concepts such as validity, reliability, triangulation or other means by which quantitative or qualitative research traditions demonstrate their rigour. We argue that *legitimacy* in this mode of research is rooted in the connection and synergies between the analysis created and performed, and the questions, theoretical framework and focus of the

study (Hetherington and Chappell 2019). We also assert that, as with all research, meticulous documentation of the processes that emerge is required such that our peers are able to understand what was done, and to make sure that the research proceeds ethically. Within postqualitative research, applying Barad's (2007) notion of respons-ability means going beyond criteria such as the British Educational Research Association (2018) guidelines to ensure that all actants are considered ethically within the research.

The notion of *intra-action* rather than *interaction* is important in diffractive inquiry of this kind. Barad (2007) created this term to denote the dynamic emergence and continual creation and re-creation of relata (phenomena that are in relation). It is intended to distinguish between a way of viewing the world in which there are relationships between objects or entities that have an ongoing separate existences (interactions), and relationships between phenomena that are emergent materialisations of matter-meaning in a dynamic process of temporary boundary-making. In a diffractive analysis, then, the focus is not on analysing relationships between the typical kinds of object and entities we might focus on, but on 'cutting together-apart' theory, data and insights to create new matter-meaning. These cuts are not made by human agency alone, but in and through intra-actions between relata that may be human or other-than-human. In this way, the diffractions are not choices made solely by human researchers, but emerge through the intra-actions between 'assemblages' of data, theory, participants, researchers, material contexts and so on. We use the term assemblages to refer to such groupings of sociomaterial networks in which agency is enacted through intra-actions, based on the work of Bruno Latour (2005) and Gilles Deleuze and Felix Guattari (1980/1987). Such assemblages are commonly denoted in postqualitative writing by the grouping together of intra-acting elements, such as 'desk-iPad-pupil' or 'teacher-whiteboard-pen'.

Despite the collection of data in the form of interviews, written responses from pupils in questionnaires, photographs and field notes, then, what shifts our work into a postqualitative space compared with qualitative inquiry is in the analytical stance. A qualitative analysis typically uses theory to frame the data and compare/connect back to the wider field, to synthesise, organise, categorise and find clarity and seek conclusions. A postqualitative or diffractive analysis uses theory to find new avenues, create threads or splays or ripples, acknowledge and embrace complexity and find points of departure for creative, new materialisations of matter-meaning. Whilst the latter diffractive stance could be construed to mean 'anything goes', the starting point is grounded in the world, explored by reading 'data' through different theoretical lenses in order to produce new thought and meaning. Lisa Mazzei (2014) offers a good example illustrating what this process can do. In reading a multiplicity of texts through one another—an extract of an interview with a woman academic who is a first generation college graduate, Barad's concept of intra-action, Deleuze and Guattari 's concept of desire—Mazzei produces new considerations that highlight the mutual co-production of bodies and words in the performance of subjectivities, that might not be possible by simply applying a theoretical stance to code data as one would in traditional qualitative analysis.

Building on this idea of diffractive analysis that brings theory and data into an intra-active relation with one another, we have developed the concept of a 'diffractive switch' to further emphasise the dialogic nature of diffractive inquiry (Hetherington, Hardman, Noakes and Wegerif 2018). We work with this concept to frame and articulate our approach to the study. In Bakhtinian dialogic theory, dialogue is understood to proceed through a 'dialogic switch' between voices, which enables others to see from each other's perspective: the switch brings the other into relation (without which dialogue cannot proceed) whilst maintaining separability between the others in relation (without which there

is only agreement and cannot be dialogue) (Bakhtin 1986). Hetherington, Chappell, Ruck Keene, and Wren (2019, p.26) argue that the dialogic switch is helpful in understanding Barad's diffractive process of 'cutting together-apart' and label the switching move in a material-dialogic intra-action a 'diffractive switch', describing it thus:

"In diffractive switching, continuously produced, boundaried, material-discursive phenomena need to switch perspectives to be able to intra-act. This is the cutting-together. At the same time, as part of the same process, they are intra-acting within a material-dialogic space and, through the intra-action, are separated and boundaried, or cut apart." A diffractive switch, then, refers to the mechanism by which dialogue proceeds, by seeing from the perspective of the 'other', in a manner that foregrounds both the other-than-human within the dialogue and the temporary and emergent nature of the phenomena that is intra-acting, or, in other words, engaged in material-dialogue. This, therefore, articulates the *dialogic* nature of intra-actions, highlighting the importance of the ongoing relation between constantly emerging 'others' in an intra-active ebb and flow. The research process described in this paper was an ongoing material-dialogue, as assemblages and phenomena constantly emerged, performing diffractive switches as the material-dialogue proceeded as questions|answers were explored. The 'methodology' of the paper is therefore effectively to follow and document the emerging material-dialogue through our diffractive switches.

Our starting point was to collect data through: semi-structured focus group interviews using material/digital stimuli, with 4–5 pupils per project, at the end of each project (hereafter Pupil FGs); individual interviews with project partners at the end of the projects, using material/digital stimuli (hereafter partner interviews); short videos were taken during three research visits per project; field notes were collected using a semi-structured observation schedule to focus on material intra-actions alongside dialogue during the three research visits per project; photographs—taken by researchers and pupils at timed intervals to encourage a focus on other-than–human materials as well as human activity; project artefacts were collected including VR environments, pupil ocean literacy work and art works.

We then read this data through a selected theory-driven question (Mazzei 2014), after which we engaged in a material-dialogic process responsive to the situation, including the disruption caused by the Covid-19 pandemic. As a result, our research apparatus (Barad 2007) included digital tools such as Padlet, OneNote and the VR space developed for the project as well as maps, string, laptops, email, Teams calls, pens, paper, bodies, etc. We also acknowledge that the study involves a process of spacetimemattering (Barad 2007) in which the research has not, and cannot, proceed in a linear march from start to finish, but instead loops through an emerging material-dialogic space as intra-actions and diffractive switches occurred with new phenomena, new ideas and new questions withlin which the original 'data' continues to present itself anew. We therefore encourage the reader to see what follows as a material-dialogue into which they are invited, and to engage with this research as an active participant. We invite you to engage in a diffractive switch: cutting together (seeing from this paper's perspective)-apart (creating new meaning or new phenomena from the intra-action).

In the next sections of this paper, we articulate our diffractive process by describing a series of four material-dialogic assemblages through which the creative materialisation of new knowledge is generated. These include a novel approach to engaging in our diffractive process through the use of the project's virtual reality environment, along with other digital spaces as a material-dialogic research space in which assemblages of data-researcher-practitioner-aquaria-articles-ideas are brought together. Within each of the assemblages we describe a series of intra-actions where diffractive switches take place as part of a

material-dialogic process of cutting together-apart to make new meaning. For each round of projects, we describe the assemblages, spaces and processes that unfolded in sections entitled 'forming the material-dialogic assemblage/s', before sharing 'pieces' responding to our core question 'what messy mixtures of natural-cultural-technological were learned through' (see below). Following each piece, we articulate briefly the new learning and questions arising from each material-dialogic assemblage in short sections entitled 'the ripples', a term drawn from the notion of diffraction wave-patterns on which Barad (2007) draws in developing her conceptualisation of diffractive analysis The last diffractive process we present creates a final assemblage of the four 'pieces' made through our diffractions, cutting each together-apart to explore the creative dis|continuities between them and inviting the reader to engage in a diffractive switch with us.

Before moving into exploring the diffractions that lie at the heart of this paper, it is important to note that our ethical stance of response-ability (drawing on Barad, 2007 and noted above), is one that reflects a world view, or onto-epistemology, of ethics, values and care. This threads throughout the work with respect to both this analysis, the wider research and educational work within which this analysis is situated, and our stance towards the environment. We refer regularly in the diffractions to the concept of 'ethics and trusteeship', which is one of the 'features' of creative pedagogies on which we draw in the Ocean Connections project (Chappell, Hetherington, Ruck-Keene, Slade, and Cukurova 2016). Ethics and Trusteeship is focused upon an ethical approach in which participants in an educational setting (and, in this case, a research setting), should consider the implications and impacts on others of their creative processes and inquiries. We therefore followed all the necessary requirements of the institutions involved in this research to gain ethical approval for the work, sought informed consent from all participants and pupils' parents, but our ethical approach goes beyond this in the use of creative pedagogies, including acting with, and promoting shared ethics and trusteeship in the projects themselves.

Diffracting the first projects

Forming the material-dialogic assemblages

Each diffraction takes place within a material-dialogic assemblage created responsively as researchers-data-theory intra-act. With the data from our first round of projects, we used a similar, though not identical process to form these assemblages. Following the first round of projects, we (the UK Higher Education [HE] researchers) asked each national team (including HE and school teacher researchers) to work with the data to select an assemblage of 12 'glow moments' from their project data. Although we intended to include students in the selection of glow moments, this was not possible due to the timing of the school lockdowns as a result of the Covid-19 pandemic, which disrupted the project and therefore the assemblages we were able to make. The notion of 'moments that glow' taps into the researchers' affective response (MacLure 2013). Data that pushed themselves forward, called for attention, were chosen according to this intellectual-affective response. The glow moments therefore came back to us, for example, in the form of selected photographs, short quotes from interviews and phrases from observation notes.

In order to work with the glow moments, we chose to select a quote (see Box 1) from which to begin our diffractive process that we had shared at an international partner meeting where we introduced the notion of diffractive analysis to the project team.

Box 1 Selected quote used to diffract with data

"Drawing on Latour (2004) and Haraway (2008), **common worlds** approaches enable a refocus on the diverse cultural [*including technological]* and natural environments in which children are enmeshed. Children's lives are understood as situated within "the real, messy, imperfect and undivided natural and cultural worlds they (and we) inherit and inhabit with other species" (Taylor and Pacini-Ketchabaw, 2017:133)" Somerville et al. (2020)

Focusing on the entanglement of people/learners with the cultural (which we interpret as including technological) and natural environments, we felt this quote reflected the focus of the project and its particular exploration of the relationships between the natural ocean, its cultural and technological connection through the pupils and teachers, school curricula, aquaria, the VR technology and creative pedagogies. Although we were not using the common worlds approach mentioned in the quote, what stood out for us was the bringing together of the natural cultural, and the notion of the entangled, messy weaving together of natural, cultural and technological as part of children's' lives. Discussion between two project researchers (Kerry and Lindsay) led to the framing of this quote as a question with which to begin responding to the glow moment data. "What messy mixtures of natural, cultural and technological environments were learned through?" This question, inspired by the theoretical quote, felt to us to offer potential for the development of insights into a range of ways in which nature, culture and technology (as a facet of culture) entangled and intra-acted as the projects and learning unfolded. It places the initial focus of the question on the'mess'—in other words the unplanned, disorganised, fluid and dynamic nature of learning as well as on the way in which different elements of the projects'mixed'—understood as cutting together-and-apart in intra-actions. This question therefore opened space for diffractive analysis in which culture, nature and technology'mix messily' in the analysis (in other words, in our writing and thinking), enabling us to consider the materialisation of power, identity, agency and time in relationships between disciplines, nature-culture, human and other than human and so on. We felt that this gives space to acknowledge our posthuman stance, in which the 'learning' referred to in the question is not solely that of the students, but also the other emerging elements which are intra-acting and through which new matter-meaning (including learning) emerges. This therefore seemed to offer a potentially rich starting point for the Project Phase 1 diffractions.

As a result of the Covid-19 lockdown, we needed to choose a virtual space in which to work in dialogue with each other and the data. Where possible (I.e. for the Spain and Denmark projects), we began by using a 360° VR image of the inside of one of the aquaria within the space created to conduct the projects. For the UK project, this was not initially possible due to slow-loading, relatively unstable footage and so a Padlet was bought into the assemblage instead. Using virtual spaces in this way seemed to be an ideal way of engaging diffractively together-apart, to work within living material-dialogic spaces of research as well as education. It also enabled other partners from each project to engage in the diffractive, dialogic process and bring in other perspectives and responses. Using the same affective agential cutting as the glow moment selection, we therefore worked in either a Padlet or a 360 space from the aquarium relevant to each national team to create the diffraction. Taking it in turns, Kerry and Lindsay cut glow moments into the Padlet or the VR scene along with audio comments, images, typed questions, quotes, theoretical strands and analytical thoughts, creating a dialogue within the space (see Fig. 1). We also asked the teacher researchers to use the same glow moments and the same padlet or VR 360 space to respond to the initial question as a second diffraction. By the time we reached this point,

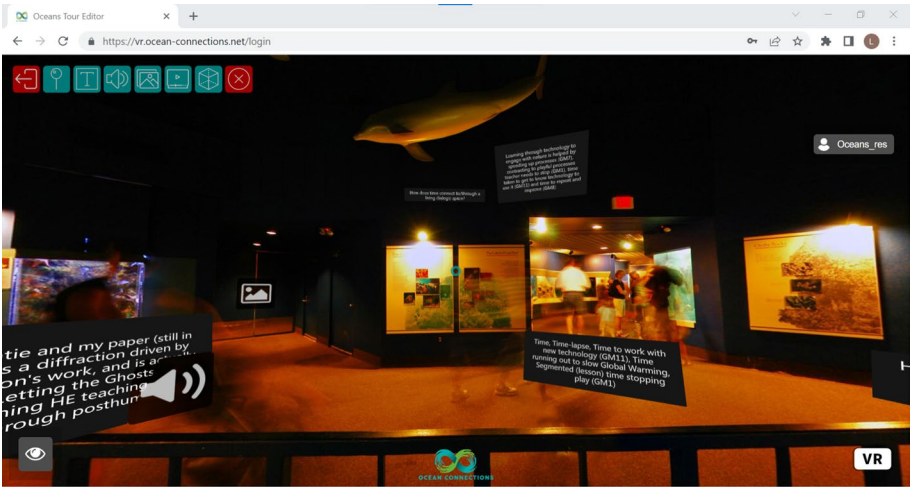

Fig. 1 An example of the VR space into which glow moments were cut

we had additional VR images for the UK site so the UK team colleague was able to shift from working in Padlet to working with a VR image for her contribution. This therefore left us with two responses to our data within online spaces (2 VR diffractions for Spain and Denmark, and 1 padlet diffraction, and 1padlet/VR diffraction for the UK).

Through this process, we created an unfolding set of material-dialogic assemblages, two per project. We then brought the two assemblages per project together to perform a diffractive switch, intra-acting the assemblages in which the HE researchers and the teacher researchers were a part. This was achieved using the digital collaborative package OneNote, as it enabled a combination of narrative writing, movement and drawing. Kerry and Lindsay each began with one of the assemblages, choosing a starting point and spiralling out, responding to data-theory-images-aquarium space-sounds passed along the way by creating a response within OneNote (see Fig. 2). This was then repeated by the other researcher moving through the space, bringing the two spaces for each project into dialogue. Finally, Kerry worked diffractively with the assemblage created from the English and Danish projects, and Lindsay with the Spanish project, to respond tolintra-act with the theory-driven question 'what messy mixtures of natural, cultural and technological environments were learned through'? The three diffractive 'pieces' which follow were created through this process.

Assemblage/diffraction 1: Irresistibly Making Kin|England (Kerry leading)

The piece

I (Kerry) have selected an excerpt from the UK OneNote that struck me and quickly connected itself with two particular readings I was engaging in (Fig. 3, with Fig. 4 showing Padlet text source).

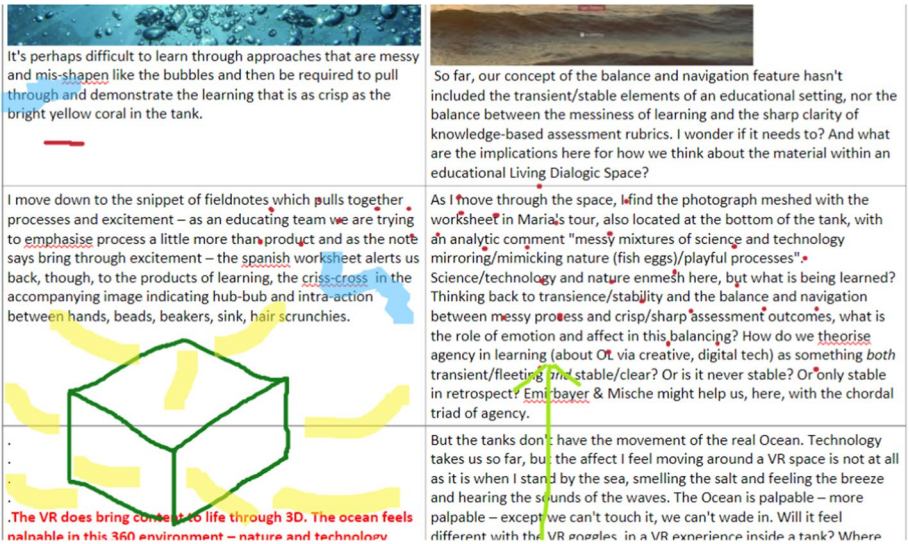

Fig. 2 Screenshot of a piece of the OneNote file: Kerry/Lindsay/VR diffractive switch

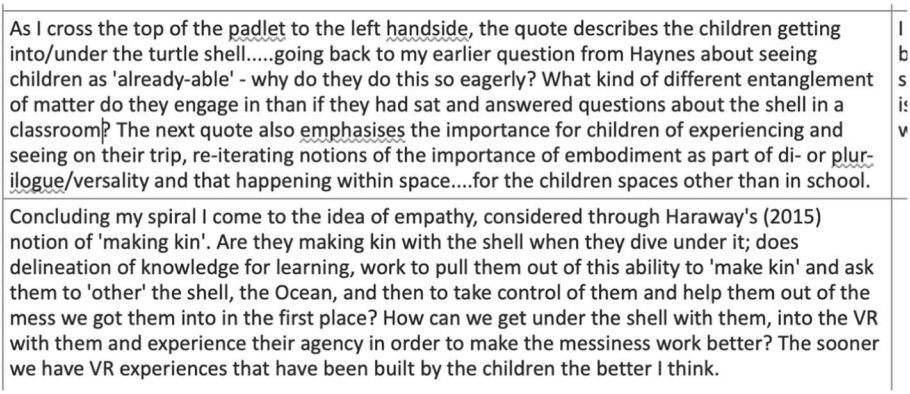

Fig. 3 Excerpt from UK OneNote

What strikes me here is that the shell is irresistible to the children. This may have been what subliminally glowed to the colleague who picked this glow moment (it may not), but it is certainly what has struck me—they want to touch it, to get under it, around it. And they do. In the OneNote screenshot above, I cut through Joanna Haynes' (2021) idea that children are 'already-able'. By this she means that they have abilities to act, think and philosophise in ways which we might ignore if we work with a definition of ability centred around a white, male able-bodied adult. Whilst Gert Biesta (2004) argues that some in education teach using a set of transmission-based, adult-derived and taught cognitive abilities, Haynes is suggesting that children are equipped with the agentic capacity for playful enquiry, to perhaps recognise better than adults, the connections with 'things' and their mutually affecting relationships (Bennett 2010), and to do this in a way which might not be conscious or articulated into words. In my cut here, I ask 'what kind of different

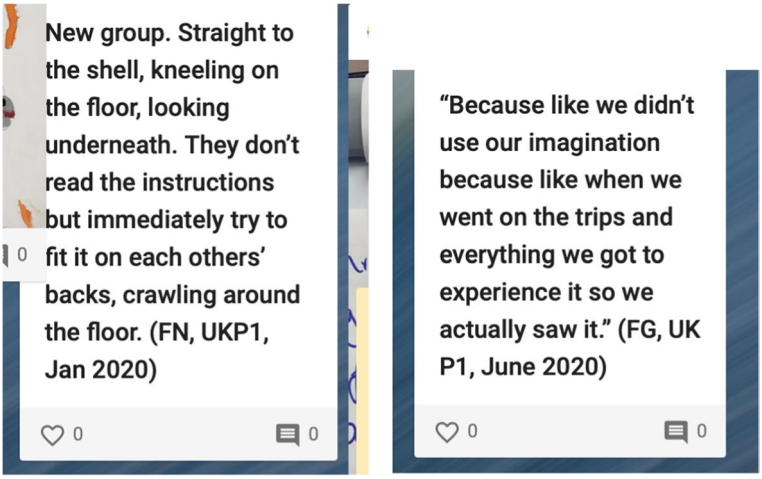

Fig. 4 Screenshots of Padlet that OneNote text refers to

entanglements of matter do they engage in than if they had sat and answered questions about the shell in a classroom? The fieldnotes show them entangling themselves with the shell trying to fit it onto each others' backs and crawl around the floor, perhaps exploring the sensations and/or embodiment of 'being' like a turtle. There is a messy mixture here of natural and cultural from the turtle shell and its situatedness within a trip to the zoo. Within this particular messy mixture the children can show themselves as already-able, as perhaps intuitively responding to the shell in a more visceral and embodied way than if they had looked at an image of a turtle in a reference book or online, or even handled a small shell in their classroom. It is important to note that this way of knowing may not be an experience that they could consciously or critically articulate; it may remain in and need to be valued as its own mode; this does however raise questions in a school-based knowledge system which is dominated by knowledge as demonstrable through verbalisation. Interestingly, the instructions from the zoo educators referred to in the fieldnotes included a true or false question as to whether the shell will fit your team-mate. They were actually engaging in an activity that the zoo educators had wanted to encourage but responding to their instinctive reaction to engage with the shell rather than stopping to read the instructions and follow them.

As I continue to spiral around the Padlet assemblage (Fig. 5), documenting my journey through it in the OneNote, I come to a tile where we have cut through Haraway's (2015) notion of 'making kin' with empathy as an accompanying concept.

When the children are exploring the sensations of the shell and 'being' like a turtle, it perhaps takes them into a more empathetic relationship with the creature than factual learning about shell size, make-up, etc. This is not to deny that knowing this information is important for all sorts of reasons, but it can dominate how science and the ocean are taught in schools (Osborne and Collins 2000). When Haraway talks about 'making kin' she calls it a 'wild category' (p. 2). It relates to questions of who lives and who dies within kinship, and "what must be cut and what must be tied if multi-species flourishing on earth, including human and other-than-human beings in kinship, are to have a chance?" (2015, p. 2). One of the arguments as stated in the introduction, for working with these posthuman and

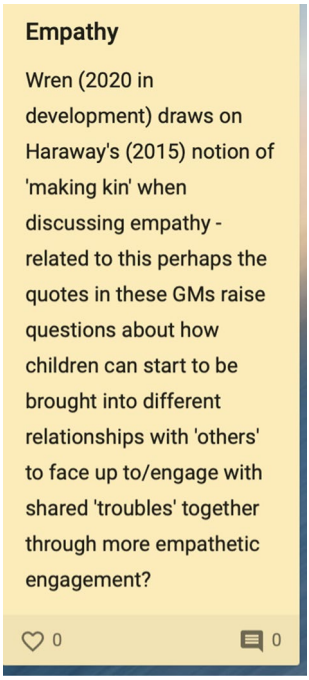

Fig. 5 Third screenshot of the padlet that OneNote text refers to

new materialist ideas in relation to educational possibilities is that they can change children' relationships with the ocean and its inhabitants. I ask whether they are making kin with the shell when they dive under it. I also wonder there whether the 'usual' approach to learning in school pulls them out of this ability to 'make kin'. Often it seems that children are asked to 'other' materials like the shell, and then take control of them and help them out (as I say in the OneNote—of the mess we got them into in the first place).

The ripples

When thinking about the messy mixtures of natural and cultural, relating back to our earlier intention to question how we can re-entangle them rather than see them as binaries, I am quite literally wondering how can we follow the children's lead and get under the shell with them in education. How can we let their empowerment and agency come to the fore? How would it be if adult facilitators explored the shell alongside the children following their intuition, making kin and becoming affectively involved with it as a catalyst for ocean literacy learning? Donna Haraway's (2015) discussion of making kin encourages this kind of thinking and comes with the slogan 'Make Kin Not Babies'. She is asking us to do this to support multispecies ecojustice. These are big ideas derived from Haraway's identification of the need to respond to the stark issues of planetary overpopulation. But as Chappell (2021) argues we need to start to address these issues within our education system rather than remaining with our heads in the sand of a transmission-based industrial model. Clearly a primary classroom is not the place for more extreme ideas such as anti-natalism (MacCormack 2020), but the messy mixture at play within this assemblage hints at ways that children can be encouraged to access and show us how they are 'already-able',

to empathise and enter into kinship, and to ask questions concerning the ethical element of this related to their own role as potential trustees or guardians who perhaps more intuitively than most adults are able to mesh nature-culture and in so doing redress the power imbalances which it might be argued are at the root of many of our Anthropocentric challenges. This can perhaps contribute to an understanding that care and kin do not always need to be directed at humans, but can be shared beyond, in order to bring different educational priorities into balance. In this case, moving beyond the turtle shell, we can think about the children making kin with the ocean on a larger scale, a notion that emerged elsewhere in the project for the children when they discussed how they would feel 'if they were the ocean'.

The thread which leads out of this assemblage and remains a live conundrum is the entanglement of technology. I am left with questions about how VR might be put to work to get 'under the shell' with the children perhaps in VRs of the turtle's own habitat. This could allow adults and children to become entangled with the turtle's world, not just its shell, to begin to perhaps co-experience its agency, as Tim Ingold (2006) suggests, engage in the practice of animating lifeworlds, in this case that of the turtle.

Assemblage/Diffraction 2: Living Bodies and Virtual Environments|Denmark (Kerry leading)

The piece

Whilst the Danish OneNote included a number of fascinating cuts, the excerpt that stood out, or glowed for us the most, raised questions as to the relationship between 'live bodies' and VR. I (Kerry) began the cut by focusing in on the glow moment which has been screenshot below (Figs. 6 and 7), which describes and portrays students physically brainstorming the notion of ocean biodiversity.

As the screenshot of my (Kerry's) writing in Fig. 8 from the OneNote shows, as a dance artist, I know how risky it can be for colleagues with little dance teaching expertise to open up a space for physical, dance-based exploration like this.

The HE research team had put forward the idea of working with the arts as a means to encourage the project's Educative Principles, so it is heartening to see this being explored. As a dance specialist it takes me to recent debates within the arts world, which as Gerry Morita (2018) states "in an era of mass digitisation and repeatability through media, that failure, roughness, the messiness of a live body and a focus on identity of that body are also radical states" (Morita 2018). Perhaps strangely we have reached a point, especially through our Covid-19 experiences, where the digital is more ubiquitous than live bodies in a studio or room together. In my experience, the young people are doing a fairly standard movement improvisation exercise to engage in an overtly embodied dialogue (Chappell,

After presentation and work with understanding the concept of biodiversity in the classroom, the students should have a more creative approach.

They were instructed to choreograph a dance expressing biodiversity in the ocean.

First phase was a physical brainstorm - what do your bodies think about ocean biodiversity. As soon as first phase of the project was presented and the music turned on, everyone started moving like all sorts of underwater animals - the room was filled with improvised dancing.

First phase was well underway. Unfortunately, the choreographies were never finished because of the corona.

Fig. 6 Fieldnotes describing studio activity

Fig. 7 Students physically brainstorming ocean diversity

I spiral from the bottom right- improvised dance. I know this is risky for partners without much dance teaching expertise. Takes me to a quote from The Dance Current (a Canadian Dance Magazine) "in an era of mass digitization and repeatability through media, that failure, roughness, the messiness of a live body and a focus on identity of that body are also radical states" (https://www.thedancecurrent.com/column/radical-risk). Gerry Morita, the author, picks up on our interest in messiness – this actually makes me spiral back to the glow moment above where Knut gets so physically, messily engaged to make his point. The radical state of live bodies is perhaps an idea to stick with alongside our VR ponderings?	Like Kerry, I am really interested in Knut's gestures described in the last GM – how we use our body-voice and intra-act with materials as we teach/learn intrigues me, and this connects with dance experiences. I also find myself connecting this to my previous musing on immersion/oversaturation and Kerry's questioning about the radical state of live bodies in relation to VR. Bodies connect in VR, we don't divest from them, but we do divest from the environment the body is 'in'. Fauville's recent work exploring ocean VR experiences when the body is immersed in water recognises this, I think.	Spiralling through to the top left, I pass GM in which Knut mimics the action of the waves and salinity measurements mimics taste. What is the role of such mimicking understood as an intra-action? What 'new' performances emerge? Related to the previous glow moment, is the student's 'real' response to a hunting fish in his immersion in VR 'real'? What is 'virtual' and what is 'real'? When we use our living bodies to gesture, tell stories, respond and perform, in ways that 'mimic', or represent, something else, is that virtual reality?

Fig. 8 Excerpt from Danish OneNote

Hetherington, Ruck Keene, Wren, Alexopoulos, Ben-Horin, Nikolopoulos, Robberstad, Sotiriou, and Bogner 2019) to generate ideas and understanding of the physicality of different organisms in the ocean. However, as Morita suggests, this is not common educational practice in many schools, and the 'roughness' of your live body experimenting in dialogue with others is more radical here than might be thought at first glance. As Ulmer (2017) has argued, from a humanist perspective, the students would be being encouraged to 'represent' the ocean biodiversity in their dance/movement (an idea Lindsay picks up on in her questioning of this idea in the OneNote). However, considering the activity through a

posthuman lens, there is a drive for non-representational practice which is, in fact, different to a traditional arts education approach: the aim is not to create a movement representation of an octopus or seaweed but to explore through movement process (perhaps connecting to process notions from the likes of Whitehead 1978) the subjectivity, or as Ingold (2006) refers to it, the 'lifeworld' of the other-than-human being explored or dialogued with. There are therefore emergent shared experiences of subjectivities here, which are generated from the messy mixture of natural and cultural elements of teaching and learning.

Figure 9 shows that in the OneNote, I am then propelled to spiral back to the glow moment, higher up in the Padlet, as is Lindsay in her response in the OneNote, where Karl gets so physically, messily engaged to make his point, as described in the fieldnotes in Fig. 9.

Marito's 'radical state of live bodies' comes to mind again. Here the proximity to Karl, his embodied explanation of an idea for which words were not perhaps satisfactory. Indeed, what he wants the students to understand is not a word-based process, it is defined and manifested through the materiality of the air–oxygen–water intra-action—we humans have developed words and language to represent this in a particular way for our needs, but these words are not the process itself, they are our noisy, spoken interpretation of it.

Whilst this episode is not using the VR as part of the teaching and learning it leaves both Lindsay and I with questions about the wider relationship within the project between live bodies and the VR. Lindsay cuts Geraldine Fauville, Queiroz, Woolsey, Kelly and

their enthusiasm). [redacted] is asking them why there is much oxygen in the water. The glow moments arrives when [redacted] is franticly waving his arms and with his body simulating the movement of the water in the lagoon and trying to explain how the "air" and oxygen along with it, is "forced" into the water mechanically and making it "very" saturated. This simple, mechanical explanation along with the "experience" of how they themselves were affected by the wind made this a bodily experience.

Fig. 9 Karl working with young people at the Ocean edge

Bailenson (2021) work in to develop thinking here. As she states in the OneNote (Fig. 7), bodies connect in VR, we do not divest from them, but we do divest from the environment the body is 'in'. Fauville et al.'s work exploring illusory self-motion in ocean VR experiences recognises this, as it tests the differences between experiencing an underwater ocean VR when immersed in water and when standing next to water, where both sets of participants are tethered to remain in the same place. In the former, participants felt that they had moved much further than participants standing next to water. Fauville et al. attribute this to the effects on the participants' sensory systems: the weightlessness in water which prevents appropriate vestibular input, meaning that visual/vestibular systems conflict is reduced and vision within the VR is more heavily relied on; and somatosensory and proprioceptive cues from the water reinforce a feeling of being in motion. For now, this remains a thread for further exploration, as we do not have the option within the Ocean Connections project to immerse those in the VR in water, however what emerges, is an alert not to see the live body and the VR as separate or in opposition.

Lindsay raises further questions as to this relationship in the third column of the OneNote which take me back to my earlier point cutting through Ulmer. If we see the live body experiences not in a humanist way as mimicking or representing but as an opportunity to experience subjectivities and process, we are perhaps able to work with a more enmeshed view of virtual reality—not seeing experiences as one or the other, but as a more than the sum of their parts. Recent research in road traffic management (Wu, Liu, Lan and Yang 2015) discusses the 'virtual-real fusion method' which uses the merger of 2D and 3D with live experiences to give the participant a greater feeling of immersion. Cutting in both Fauville, Queiroz, Woolsey, Kelly and Bailenson (2021) and Yuezhou Wu, Liu, Lan and Yang (2015) suggests that the real and virtual can very much be in an enmeshed dialogue within these messy pedagogical mixtures, and moving forward from this premise rather than their separation, could be fruitful for developing this thread.

The ripples

Returning to the question of what messy mixtures of natural, cultural and technological environments were learned through, this assemblage shows us how engaging with our living bodies in learning is not common practice, and leads us to ask how can living, learning bodies be brought through more pedagogically, not just to represent ideas, but to more fully engage pupils physically and socially in other-than-human lifeworlds; attending to notions of embodied dialogue as a means to encourage this extension. It also raises questions as to how we can more fully engage with real, fleshy bodies (human and other-than-human) and the implications of the cultural (and natural) identifiers which they bring with them. We note that our study dominantly worked with white students who despite globally being in the minority, exercise huge amounts of white privilege. Bessie Dernikos (2020) demonstrates the violent injustices marked into the flesh of global majority black and brown bodies in society and education, and asks for us all to consider the flesh as materially influential in educational assemblages which generate racial identifiers through bodies and affects which can create oppressive racial distinctions. How can we pay greater attention to living bodies in this kind of environmental education in ways that do not assume homogeneity between humans? How can we acknowledge the embodied injustices against a black majority brought about through historic white privilege, and find ways to address these? This particularly relates to parts of the current climate emergency such as Indigenous people being disadvantaged by rising sea levels and loss of lands caused by Western overconsumption.

How might taking a more embodied and potentially empathetic approach to ocean literacies contribute to addressing situations such as this? And how can we also open humans up to the multiple forms of embodiment and materiality of other-than-humans. Instead of words and noisy verbalisations might diverse, embodied engagements do a better job? Finally, the assemblage also encourages us not to see the live body and the VR as separate or in opposition, an alert to aim to work with a more enmeshed view of virtual reality in the future. Whilst the teaching teams in Ocean connections did not wholeheartedly achieve this enmeshing of the live body and VR, in many respects because of Covid restrictions which stopped the 'live' teaching and learning from developing, our learning here is about the potential for investigating how the virtual and embodied might be brought into relationship better in the future to address wicked problems.

Assemblage/Diffraction 3: Messy mixtures, spacetimematter and environmental activism|Spain (Lindsay leading)

The piece

Diffracting with the Spanish Project 1 Glow Moments within a VR space was the first set of data I (Lindsay) worked with in this project, in this way. One of the first things that struck me, that really stood out, was the 'ghostly' nature of the moving features of the scene (the people and moving organisms), in stark contrast to the sharpness of the material cultural and technological artefacts (the glass tanks, the building, the wall displays). Cutting into this scene with glow moments, into this ghostly space, I connected with Barad's (2010) paper 'Quantum Entanglements and Hauntological Relations of Inheritance: Dis/continuities, SpaceTime Enfoldings, and Justice-to-Come'. In this paper, Barad playfully disrupts the typical continuous narrative to explore ideas of the diffraction and intra-action through spacetimematter via 'scenes', inspired by a Derridean reading of Macbeth alongside Frayn's play *Copenhagen* and the history of quantum physics. I am mindful that in our diffractive process described in this study we are re-turning, working dis/continuously through space and time and matter, continuing to create new questions and insights. I am not describing the Spain OneNote diffraction in a chronological sequence but I am jumping around through VR/OneNote/theoretical reading and a material-dialogic spacetime.

Kerry picks up on my 'ghostly' comment within the VR space to draw on similar ideas from Avery Gordon, used in her paper with Katie Natanel and Heather Wren (2021) to also explore how the past/present/future cut through one another. This sense of nonlinear spatio-temporal intra-activity is apparent in some of the glow moments cut through the VR scene in which time comes to the fore as a commodity (enough time, time running out), a disruptor (time to stop play and move on with a lesson), and part of a process (technology to speed things up or slow things down) (see Fig. 10, showing the detail of the glow moments mentioned here in relation to Time). Time is a crucial dimension within learning that is a part of the 'messy mixture': the natural, cultural, technological assemblage with/in which the pupils are learning is mixed in a nonlinear spatio-temporal space, contributing to the messiness itself. A researcher question dropped into the space in response to the data-space assemblage asks, "How does time connect to/through living dialogic space?" (see Fig. 9). This concept of time (or really, entangled spacetimematter) as a key aspect

Fig. 10 Glow moments cut into the VR focusing on Time

of learning about the ocean and ocean Literacy stands out for me in the Spain material-dialogic assemblage.

As I continue to move through/think with the assemblage of VR-data-OneNote-theory I see spacetimematter connected to transience *and* stability in learning with/about the ocean, nature, culture and technology. For example, within the OneNote and the VR, a bubbling sound from an aquarium tank 'sets the atmosphere' (VR Space 2), and Kerry starts her tour of the VR space in the OneNote here with an image of bubbles: messy, uneven, and unpredictable where the image of the tank is clean and crisp in comparison, much like the transience of the humans in the VR space compared with the built environment. Kerry comments 'it's perhaps difficult to learn through approaches that are messy and mis-shapen like the bubbles and then be required to pull through and demonstrate the learning that is as crisp as the bright yellow coral in the tank'. Bubbles are transient and dynamic, like many of the experiences and insights we have in school classrooms. In these messy

learning processes, learning is often defined from a cognitive perspective as a change in long term memory (Willingham 2021), but, drawing on Barad, such a change is not ultimately fixed and stable, but an ongoing emergence of matter-meaning, once again situating time strongly within education and learning.

Cutting into the diffractive writing, here I (Lindsay) shift into a space of reflection rather than diffraction as I felt disconnected. I find myself returning to the same ideas, turning them over and over and thinking about them again, rather than moving into a new space. I feel unable to 'cut apart' into a new space, unable to 'diffract', with nothing new emerging from the assemblage of VR-OneNote-theory-me. Rather than leaving this out and continuing with the writing as though the process was smooth and straightforward, I include it here as part of the diffractive process as my thinking shifts towards exploring activism: As I write, doodle and think with the material-dialogic assemblage here, I find I am 'stuck': reading the OneNote, moving again in the VR space, and reading a paper by Barad (2010), which the ghostly images in the VR space has reminded me of/connected me with, exploring time and an 'ethics of entanglement'. I pause. I feel like the VR and OneNote diffractive readings are ghostly, slipping through my fingers. I can feel insights into pedagogy, and the idea of learning through 'messy mixtures of natural/cultural/technological' on the edge of my brain, slipping in and out of view, haunting me. Academia as a ghostly intra-active practice of meaning-making-mattering. I wonder how much learning for school children feels like this, not the linear march of progression through a carefully sequenced curriculum…I stand and move, press play on my music stream (The Interrupters, Take Back the Power—and am reminded of the notion of activism further down the OneNote). Adding this new musical dimension to the intra-acting assemblage seems to help me shift once again into a diffractive space.

The notion of activism enters into the OneNote, with Kerry responding to the VR to state 'The children have the right to ask—how is this enough?' alongside a shot from the VR space with a child's hand on the side of the tank and the question 'who is on the outside, us or the fish?' (Fig. 11).There are questions of intra-action between 'others' in this OneNote section, an agential separability (Barad 2007) between humans and other-than humans, between those

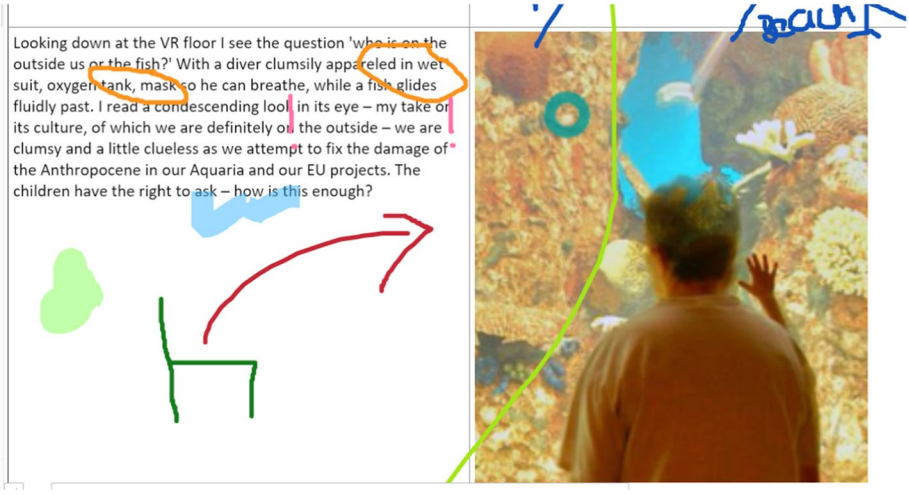

Fig. 11 Screenshot of the Spain Project 1 OneNote. "Who is on the outside, us or the fish?"

outside and inside the tank, between terrestrial and marine and, for me reading back in the here-and-now, the spatial aspect of spacetimematter in learning about the ocean. I think about how the VR technology enables us to both enter, and fail to enter, the aquatic space, as Kerry comments on the palpability of the ocean in the 360 environment whereas I note the affective difference of the VR space compared to the ocean itself. Glow moments in the Spain VR diffraction show pupils' using AR technology to bring flat images on paper into 3D space, and using iPad and AR to look at organisms, asking 'Is this alive? What is it? Can I touch it?' again highlights the dis/connections in space and time between pupils and the ocean during their learning in this project.

Kerry asks in the OneNote 'the children have the right to ask—how is this enough?', before moving on and, inspired by Maria's musing on fantasy, magic, imagination and her sound file in the VR with 'ominous music' linked to the cultural space in Aquarium Finisterrae about Verne's 2000 leagues under the sea (see Fig. 12), Kerry comments on the need to 'take this more seriously and learn before it's too late'. There is a sense of urgency here, which brings me back to time as part of the messy mixture of natural/cultural/technological: ocean and environmental education has an activist elements as time runs out to mitigate damaging anthropogenic impacts on the ocean, on the climate, on the Earth. I am prompted by this to ask 'does the creative, cultural element (of the nautilus descent, see Fig. 12) entangle with the cultures of science that resonate through the aquarium? What aspects of this space manifest in pupils' learning? As with activism, there is a time-based element to the notion of ethics and trusteeship in creative pedagogy that perhaps needs to be brought to the fore. Is activism the aspect of ethics and trusteeship in creative pedagogy a key link for ocean Literacy—activism can blend sci-culture, art-culture, tech-culture AND nature…?' Teaching about issues of scale with respect to the ocean, and Deep Time, is challenging (e.g. Dodick & Orion, 2003), but understanding space and time appears to be important for children to understand the ocean and the environment.

Laid over the OneNote, at the bottom, is a drawn image of arrows labelled time, waiting, and then an arrow taking me back up the OneNote to a point where both Kerry and I focus on a glow moment—a photograph of pupils making model 'fish eggs', alginate beads, using a scientific process. Pupils are excited by this as a playful process. It meshes science and

Fig. 12 Image of steps down to the 'nautilus' exhibition, Aquarium Finisterrae, A Coruna, Spain

technology to mirror/mimic/model nature and I begin to think again about the messiness of the learning process as manifested here in contrast to the clarity of the worksheet and crisp assessment outcomes, asking questions about the role of emotion in the balance between messiness and clarity, and wondering 'how we theorise agency in learning (about ocean literacy via creative, digital technologies) as something *both* transient/fleeting *and* stable/clear? Or is it never stable? Or only stable in retrospect? Cutting these glow moments with Mustafa Emirbayer and Ann Mische's chordal triad of agency (1998), and with Barad's (2010) thinking, I begin to consider what agency within a chordal, dis/jointed 'ethics of entanglement' (Barad 2010) might mean for an edu-activist pedagogy in environmental education. Emirbayer and Mische (1998) argue that agency, enacted at any given moment, consists of a 'chordal triad' of three temporal elements: the projective, the iterational, and the practical-evaluative, which are all simultaneously present to different degrees in any moment of (human) action. The projective element is connected to an imagined future towards which agentive action is creatively oriented. The iterational element is about drawing on experiences of the past to guide present action. The practical-evaluative element is about active selection of one of a set of alternative possibilities in the light of present perspectives on the evolving situation. It should be noted that Emirbayer and Mische's theory of agency is a human-focused one, unlike Barad's agential realism, but I would argue that within a posthuman framework where material-discursive intra-actions—agential cutting together-apart—are productive of new matter-meaning within the world, these three elements are still useful in considering how past, present and future are all entangled within such agential intra-action, with implications for ethics and thus for educational environmental activism.

The ripples

Working with the material-dialogic assemblage of glow moments/VR spaces/one-note/Kerry/Maria/Lindsay to respond to the question 'what messy mixtures of natural/cultural/technological were learned through', within this diffraction we see the notion of time threading through space and material: in other words, the messy mixture as a performance of spacetimemattering (Barad 2007). This raised questions about how teachers working with creative and digital pedagogies to teach about the ocean might work with and teach about time, connected to the ocean literacy principles in which it is both present and not present (NOAA 2020)—it is not explicitly stated in the principles but is there in the processes, scale and interconnectedness of the ocean. Arising from the piece above, such teaching using creative pedagogies could connect with time through the notion of ethics and trusteeship, and therefore with activism through education. Time, like power, is an inherent dimension of ethics, and, drawing again on Emirbayer & Mische's (1998) chordal triad of agency, we can think of ethical relational agency and power as acting within intra-actions with orientations to the future (projective), present (practical-evaluative) and past (iterational) at the same time. In doing so in environmental education such as education for ocean literacy, we must consider the role both nature and culture/technology play together in our ethical stance within the entangled flow of time, accounting for this in our curriculum creation and enactment. One possible new diffractive reading that would be interesting to explore further but is beyond the scope of this work is connected to the concept of epistemic justice (de Sousa Santos 2018), perhaps acknowledging that different kinds of

knowledge about, and perspectives on time are present for different human and other-than-human participants, and from different disciplinary and cultural traditions. Reading the notion of Ocean Literacy, examples from our projects, and texts drawn from writing about these traditions and epistemic justice and the concept of time would potentially offer a rich diffractive analysis that would enable new insights that could assist teachers and learners in engaging with time as a potentially challenging concept, in an ethical way.

Diffracting the Phase 2 Projects

Forming the material-dialogic assemblage

Working with our second set of projects from the three partner countries, we began with a similar process, asking colleagues from each country to select 12 glow moments between them from their country's Project 2 data. This could be anything from an interview quote to a screenshot from a VR platform.

Drawing on reading around diffractive methodologies within education and the sciences, we began to experiment with our thinking (Ulmer 2017) on how we might work with the Project Phase 2 data. This was all with the intention of further deepening our response to our main research question: what messy mixtures of natural, cultural and technological environments were learned through?. We considered a range of 'recasting' options put forward by Taylor (2017) including Ian Bogost's (2012) technique to use speculative fiction to summon up the life of the object/s, in this instance perhaps the ocean literacy classroom—so an invite through the data to 'think like an ocean" (drawing on Leopard's 'Think like a mountain' instruction to ecology students, Luke Bennett 2016). We also considered techniques such as writing a letter to the ocean, creating a poem using data, diffracting with something other than theory (and perhaps not words)—could we diffract with e.g. an image? We considered writing with interruptions (Raghavan 2020). We also considered moving away from the diffraction methodology which has its heritage in physics. With a focus on the ocean what biological or geographical metaphor might we use? We considered symbiosis, parasitism, evolution or Gaia (Konopka 2002). We also knew we would like to make a connection between Phase 1 and Phase 2 data given that in most cases they had been generated from the same groups of students and project continuations.

Ultimately, we decided to find our own combination of these to let the ocean into the analysis. We found a visual map of global ocean currents. We then collated all of the questions that had been asked in response to the project phase 1 data OneNotes and numbered them. We marked off on a piece of string a length equivalent to the latitude lines on the map we were using. We then laid the piece of string over selected ocean currents, starting from Europe and following a particular ocean current line—where the string intersected as ocean currents intersected we marked where this was on the crossing string and counted along the string to select the closest numbered question on the piece of string. This gave us one of the questions from our diffractions from phase 1 to work with in our phase 2 project diffractions:

- I wonder if the balance and navigation feature should include transient-messy/stable-knowledge based elements of an education setting? And what are the implications here of how we think about the material within educational living dialogic spaces?

This question had been raised in order to deepen understanding of pedagogical moments which might be transient or fleeting contrasted with knowledge-based elements of ocean literacy which might be scientific parts of shared curricula or teaching plans. The question aims to unpack how teachers and students balance and navigate transience and stability. In particular, the question is interested in how this works within dialogic spaces, as defined in the *Posthuman creativity and creative pedagogies in STEAM education* section of this article.

In applying this to the phase 2 glow moments we focused on the three elements of transience, stability and dialogic spaces, and decided to create three found poems (Patrick 2016) of words and images. One of the authoring team (Kerry) wrote the poems with the intention of challenging the traditionally accepted role that prose plays in academic writing, and to offer an alternative means for analysing and working with data for both researchers and readers. The process involves collating found data quotes and images from participants in order to use poetic form to create emotive, imaginative diffractions out from the words and the images. There was one found poem for each country; the Danish found poem is longer than the English and Spanish as the glow moments were written about in a more extended way. Once the poems were written we asked a literacy expert to help us to critique and develop them as poems. In order to bring them into conversation with the other-than-human elements of the data in the aquaria tanks, we placed the three poems into a VR environment.

Lindsay was then inspired by this process to suggest the broader structural notion of diffractive switches. Musing on this, we used this concept to structure this paper. And, as a final 'diffraction', we cut our four diffractive pieces together/apart using the notion of the diffractive switch in the material-dialogic assemblage that is this paper. This is summarised in the final section of the paper 'diffracting diffractions'.

Assemblage/Diffraction 4: Found Poems|Transience, Stability, Dialogic Space|SpainEnglandDenmark (Kerry leading)

The piece

The question that the ocean currents selected focused on the relationship between transience, stability and dialogic space. So we responded to this question to make found poems around:

transience

stability

dialogic

space

Figures 13a–c, 14, 15, 16 and 17 are images which were used in the poems and are intended to be viewed and integrated as part of the poetic interpretation of the reader,

without being 'translated' into Figure titles in words for the viewer by us as researchers. Please view the images in this spirit within the poems.

POEM 1 [UK Project 2]: I Knew

(Fig. 13a,b,c)

I knew that there was plastic in the ocean
Scared, careless
1Stop chucking plastic things on the floor
Sounds of disappointment

POEM 2 [Spanish Project 2]: It came out great!

I like it better because we don't have a time limit
In individual work we missed
the partner next to us
In groups, we didn't have to make it on our own

(Figure 14) It came out great!

POEM 3 [Danish Project 2]: Huts, cuts and 'true' grey

The day starts like normal
[but] the "feeling" is excitement
(rectangular net of galvanised rebars (50 mm × 50 mm))
Scale drawings to design
How to best cut?
So that each side has "closed" squares of rods
Students helping each other understand
a precise, sharp bend.

Strong odor of rotting shellfish greeting their senses
Students intrigued by the storytelling – sharing small stories of their own
Feeling the different structure—exterior and interior

(Fig. 15)

A warm, sunny morning
Each biohut inspected; officially "approved"
Posing more challenging questions to the students, some old fishermen showed interest
– the students trying to convince them
that this could actually improve biodiversity

The camera is placed on a float; stable in the water
The weather is calm; warm and relaxing
A lot of algae and muscles growing on the biohut
One student spots a small fish
Then another
And small shrimps
And a crab

Students are organized; in the same groups as they built their biohut
Impatient because we cannot help them

As fast as they would like
To get the video started

They are impressed of how real it is
That it feels like they are in the water

(Fig. 16)

Some lose interest because the technique makes is too difficult

(Fig. 17) a clear view

The stingray jumps up so high that it cuts Søren's finger
Surprise
The pupils are going to feed the rays
Certain respect while they stick the squid arms into the water
Intensity

All the water has boiled away
Puzzled by the fact that three instruments do not give the same "result"
What the "uncertainties" are of the different instruments

There are many variations of grey
To use the whole gamut of grey
To try to capture the "true" colour

As much as possible we hope that these found poems of words and images can be engaged with as is. We go back to the eminent arts education philosopher (Eisner, 2004) who reminds us that the meaning is in the form. The intersection of words and images in the three poems above explains itself in those intersections, in how words complement each other, how they are spaced on the page, how they are ordered and juxtaposed alongside images. Lucinda McKnight (2016) writes more recently about poems as part of post-qualitative inquiry. She argues against using poems for reflection or representation but sees them as a response, a means to engage with the materiality within pedagogical spaces, and as an experiment rather than literature as an aesthetic product. She also describes a poem as diffraction in action which splays differently for each of those who engages with it. We offer the three poems above in this spirit.

The ripples

So, for us, the poems offer insight into an idea that has emerged from the poetic process which relates to our question regarding what messy mixtures of natural, cultural and technological environments were learned through?—making the invisible visible. We are considering this both from the perspective of the poems themselves doing this, and from the perspective of the Ocean Connections VR and creative pedagogies doing this. For this reason, we have also chosen to insert the poems into one of the Ocean Connections VR environments as shown in Fig. 18a–c. This reinforces the idea of making the invisible visible through the poems within the VR.

With their space for the material (McKnight 2016), we experience through creating and perceiving the poems, elements of the messy mixture of nature, culture and technology that are made visible, tangible, sense-able by the poems: for example, odours of rotting shellfish…feeling like they're in the water. This allows for a pedagogic immersion not possible through traditional means.

Alongside the poems' ability to make the invisible visible through form/structure, etc., we also see this in the VR and creative pedagogies that are articulated within the poems. Invisibility is much discussed in feminist and decolonial studies to highlight what is being missed. For example, Bernier, Rice, CBE and Durkin (2019) use it as a tool to spotlight issues to do with race and slavery; Caroline Criado-Perez (2019) uses it to expose gender data bias. If we cut this use of visible/invisible into the poems above and draw out the thread we can perhaps better see how VR takes children into inaccessible and previously invisible worlds for which prior to this they would not need to care because it was not really in their sights (see UK Poem 1: I knew), making them attend to these worlds more and differently. The invisible/visible thread also perhaps draws through elements of creative pedagogies. This includes these new kinds of spatial possibilities, as well as the notion of ethics. The latter is often difficult for colleagues to grasp as part of creative pedagogies—what is it, why is it there? It is about teachers and children considering the ethical impacts of their creative choices, beyond the classroom. And yet when it is palpably apparent within this project's practice it does raise questions of care (see Irresistibly Making Kin above) and responsibility, which urge students, teachers and researchers to sit up and take action, working with the notion that they have a shared ethical responsibility with the ocean to do things differently.

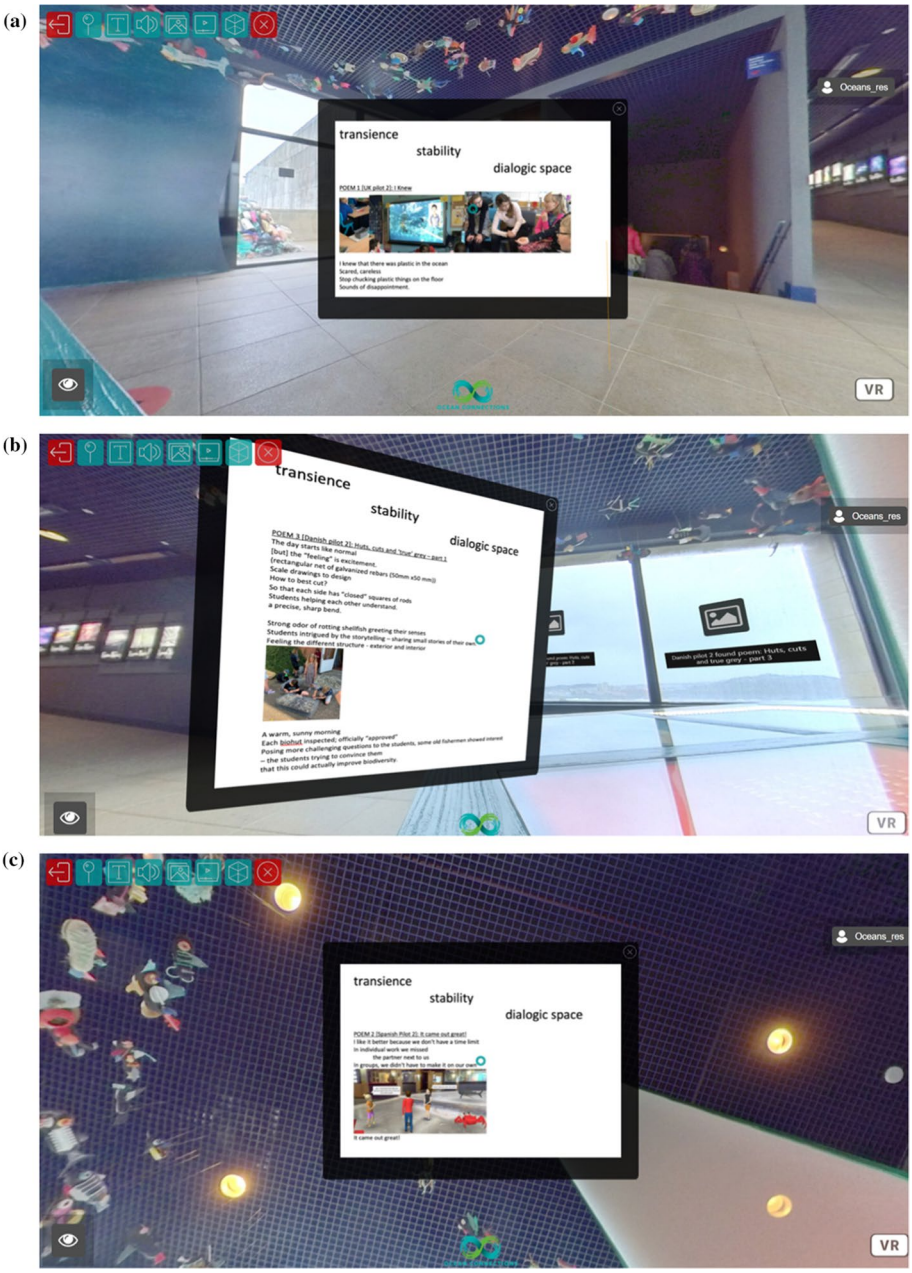

Fig. 18 **a–c** Screenshot of poems within VR environment

Michael Hakansson et al. (2018) provide a useful insight into the political tendency in environmental and sustainability education which we can helpfully apply here. They see the political tendency as deriving from the question of "how to organise social life recognising that this inevitably requires decision-making about different and competing alternatives" (p. 95), which has close parallels with our understanding of ethics and trusteeship within our pedagogical framework. In this last diffraction we can see the empathetic caring that is triggered and nudges children and their parents towards activism. In applying Hakansson et al.'s scheme, whilst we can say that the students were engaging in conflict-oriented deliberation around the ethical and emotional issues surrounding the ocean, we cannot know how far this developed into activism. Although we do know that students had become more aware of the possibility of activism: "Yeah, we learnt lots about her [Greta Thunberg] and she was really young. When she started her project, didn't she? She achieved so much" and went on to discuss ethical environmental issues with their parents or change their habits at home. For example one student said "… I went through the PowerPoint [to] show my mum how harmful it is…different things have feelings like us and thoughts". And another said "while seeing the other dangers that have happened in the ocean. I thought of being vegetarian". And another said "I used to just put everything in the brown bin but now I realise how much is destroying the ocean I put it in the right bins now." Other students talked about how they wanted to influence others to take action, for example stating that '[I'd] like make a little group or something. Oh, we'll go to, like, town and we'll make, like, quite a lot of posters. And then stick them up on lampposts and buildings that you can actually put posters up on and make, like, stands all around there. And like, educate people about the problem." There is then perhaps a case to be made for the practice of making the invisible visible through VR, as a future tool for greater social engagement with environmentally focused STEAM education.

We would like to acknowledge these are just a few of the possible ripples from this diffraction and, especially given the poetic nature of this last diffraction, we invite readers to engage in their own thinking and responding journeys through the political, cultural and ethical literature and lenses that they are each familiar with.

Diffracting diffractions

Each of the above four assemblage/diffractions performs diffractive switches to create new meaning through material-dialogue. They bring together OneNote/VR/researchers/data and explore new 'pieces' of matter-meaning coming from each unique intra-action of these elements. The final diffractive switch within this paper cuts together-apart the ripples coming out from each piece.

Forming the material-dialogic assemblage

Re-viewing the introduction to this paper, here we work with key themes from the literature discussed there with respect to: the push towards transdisciplinarity in STEAM; the use of technology in STEAM; and the use of creativity and creative pedagogies in STEAM. We cut these together with the ripples from our diffractions to provoke further questions for our readers.

The piece

How can adult educators follow children's lead (their empowerment and agency) into making kin as an affective catalyst for ocean literacy? How can VR help learners (children and adults)'make kin' and co-experience the natural-cultural-technological) world as enmeshed rather than polarised?	How can creative pedagogies surface the question of time that is present and not present in the ocean literacy principles? What does this learning with time do in the ethics and trusteeship element of creative pedagogies and ed-activism? What is the role of different ways of knowing about and thinking about time in environmental education?	Where living bodies are dis|continuous with/ in a VR space, what does this mean for embodied dialogue and learning? And how can we attend to living bodies without assuming homogeneity between humans, or other-than-humans?	How can teachers and students learn with immersive creative pedagogies and digital technologies to make the invisible, visible? And how might this encourage care for, and social engagement with others which were previously inaccessible?

Bringing these ripple questions from each of the four diffractions, we see the dis|continuous intra-actions of data, theory and thinking in our creative making of new matter-meaning with and through the 'diffractive switches' described in this paper. In asking 'what messy mixtures of natural-cultural-technological were learned through?', we see in these 'ripples' that these natural, cultural and technological worlds experienced by the children in this project are both continuous and dis|continuous with each other, providing, as Barad (2010) argues, grounds for creativity and learning that is both continuous and discontinuous with learning that has gone before.

The next ripples

From the wider perspective of STEAM education, this diffractive work raises new ideas and questions with respect to how transdisciplinarity, technology and creative pedagogies can contribute to debates within the field. The research shows how nature and culture can be combined rather than seeing them as binaries, demonstrating practices which might be employed in other teaching situations as to how nature can be brought to the fore through making kin activities (Haraway 2015) which have the potential to lead to more ecojustice activism in education. The research outcomes also show how adults could better trust children and young people's intuitions for trusteeship of this kind, in order to better respond to the ocean's Anthropocentric problems. And it raises questions about how VR and living embodied practices can be enmeshed, through art forms such as dance, and employed in the future to animate lifeworlds to support these processes. Although it leaves questions remaining as to disciplinary power imbalances within STEAM practices, especially during the Covid-19 era. This understanding of living bodies in action does, however, bring with it a contribution to STEAM education around how we work with cultural and natural identifiers (Dernikos, 2020) and should better see the flesh as materially influential. The diffractions ask us to consider how we can work towards understanding that not all humans are treated the same in ocean literacy, and that white privilege could be challenged through embodied empathy and dialogic practice.

The research outcomes also contribute to our practice and understanding of spacetime-mattering (Barad 2007), showing how working pedagogically with time (its existence through past, present and future) and space (the sheer scale of its presence and its watery spatial manifestation) can be beneficial to developing ocean literacy. In addition, there are implications for pedagogy elsewhere in science education with respect to the challenges of scale in relation to Space and geological time, both of which children find difficult to grasp in part due to the large numbers involved and the unfamiliarity of the environment. These new understandings of pedagogy are shown to have the potential to fuel activism through better enactment of trusteeship in relation to the ocean as an entity at a scale of space and time significantly different to human perspectives, and to offer examples of how this might be developed in practice.

The diffractions also use different media including VR itself and poetic form to engage the research community differently in this research and to offer these as examples of both pedagogic and research tools for the future; both mechanisms offer immersion for the reader and engager, and take them on imaginative journeys which are of a different order to traditional academic prose. The poems especially tap into the role of the arts in sustainability activism, showing how this ocean literacy work can trigger fledgling activist beginnings for some of the children.

This work has also given us, as researchers embedded within these assemblages, new digital tools (e.g. VR and AR) for our postqualitative research which have opened doors onto new previously invisible knowledge and ways of questioning. We highly recommend colleagues engaging in playful research in these spaces too. Finally, whilst we turned to these new digital tools because of Covid-19 restrictions, we remain troubled by our ensuing detachment from the data sources. Lockdowns forced us to be pushed apart online and where we were hoping to work with postqualitative practices which could include the actual ocean, children, teachers and fellow professionals—this was simply not possible. We look forward to continuing our research journey to more fully include others of all kinds.

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Declarations

Competing interests The authors declare no competing interests.

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Kerry Chappell is an Associate Professor at University of Exeter where she leads the MA Education Creative Arts Programme and the Creativity and Emergent Educational Futures Network. Her research (funded by, e.g., AHRC, ESRC, EU Horizons) focuses on creativity in education, specifically in the arts (dance) and transdisciplinary settings, and how creativity contributes ethically to educational futures. She is also a visiting lecturer at the Danish National School of Performing Arts and an Adjunct Associate Professor at the Western Norway University of Applied Science. She is co-convenor of the BERA Creativities SIG and an editorial board member for *Thinking Skills and Creativity* journal and *Research in Dance Education* journal.

Lindsay Hetherington is an Associate Professor of Science Education at the University of Exeter where she is Co-Director for the Centre for Research in STEM Education (CRISTEME). Her research is focused on understanding science education using sociomaterial theories with a particular focus on education for sustainable futures and environmental education. With this in mind, her research regularly takes a transdisciplinary perspective including a focus on creativity in education. She is an editorial board member of *Research in Science and Technological Education*.