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Taking the Complex Dynamics of Human–Environment–Technology Systems Seriously: A Case Study in Doctoral Education at the University of Luxembourg

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Our existential sustainability challenges involve human–environment–technology systems that are complex, dynamic and tightly coupled. But at Universities, knowledge, in teaching and research, is mostly organized into discrete parcels, the disciplines. These are further divided into the categories of natural sciences, social science and the humanities. This paper addresses the question of how in their training of researchers, universities can equip them to better understand their roles and also to act as change agents. It describes a doctoral school course in transferable skills that is offered across faculties. The unique aim of the course is to provide a space for reflection on different research paradigms and the way they differ in their framing the role of a scientific researcher in pluralist societies that face existential challenges. The pedagogical framework and approach of the course encourages questioning one's own ontological and epistemological assumptions about the constitution of our world and how we might better understand it in dialogues with participants who come from diverse disciplinary backgrounds. The course includes discussions of: what is a discipline, and how disciplines differ in their understandings of the world and of the role of science within it; how tools and representations can shape or breach disciplinary paradigms; how instrumental science and interdisciplinarity can raise the dilemma of rigor or relevance; how complexity, contradictions and values are embraced in responsible research design, and last but not least we discuss the relation of science, progress and open futures. The course introduces diverse more recent approaches to scientific inquiry that harness the potential of democratizing science in our networked knowledge society, including critical interdisciplinarity, post-normal science, citizen science and transformative sustainability science, that complement normal disciplinary research practices.

Keywords: discipline, critical inter-disciplinarity, complexity, science, doctoral school course, responsible research and innovation (RRI)

INTRODUCTION

In the twenty-first century we not only are entering an era of less stable living conditions on planet earth, as suggested for example by evidence on the sixth mass extinction of species and climate change, but some researchers also point to the increasing instability of our knowledge systems (Hulme, 2009; Maggs and Robinson, 2016). Contemporary science faces a wide range of challenges. First and perhaps foremost, today, in the face of civilization's complex and existential sustainability challenges, there are urgent demands on science to be at service of society. The EU Horizon Europe programme will, for example, call for more and ever larger "mission-oriented research projects." Tensions between responsible and "embedded" research and the autonomy of science will be further pronounced (Tassone and Eppink, 2016).

Furthermore, in many disciplines conceptual simplifications and constraints hinder researchers from considering complexity, contingency, contradictions, and open futures in a manner that may be required to locally and meaningfully produce evidence for action on sustainability challenges, or even lead to contradictory advice from different disciplines or fields of knowledge. The credibility of science suffers due to divisions of experts on crucial and popular issues, exposing science even further to dangerous populist attacks.

Doubts are also spread by reports on the internal replicability crisis (where methods leading to results published in peer reviewed journals can't be replicated, impairing quality assurance in peer review—e.g., Bishop, 2019). Public trust in science is further undermined by instances of manipulation by vested interests due to the continued "industrialization" of science, or its proximity to industry and commerce (see also Ravetz, 2018). Several of these issues can be seen as a consequence of the way that science in general is organized, which can also lead to phenomena such as perverse career incentives of scientists from impact measures to publish in quantity rather than quality.

Accordingly, the understandings of science and its relation to society, morality, and individual responsibilities of scientists are changing rapidly and drastically. However, in our virtually connected information society there are also many new opportunities to fundamentally rethink knowledge production processes, including in science, and who plays what role within them in the (co-)creation and legitimation of new knowledge. All these related challenges and opportunities highlight the need for education among researchers about the nature and role of science in the contemporary world.

This paper describes a doctoral school course designed to offer researchers, most at the start of their career in science, a space for reflection on their research projects in view of these critical challenges to both science and society. This course starts from the assumption that these questions can be made explicit and deliberated on, within and across all disciplines and transdisciplinary approaches. We believe that such a reflection will be a requisite for the maintenance of public trust and improved teaching in schools and at university level. Furthermore, the goal is to equip researchers for reflexivity and in a next step, to invite them to return back to their respective research groups and present these debates within their circles of peers, where they can act as change agents and multipliers across faculties and research.

This paper first presents a pedagogic framework, a set of competences and a learning environment that are the basis for how we understand and organize "learning." This pedagogy largely relies on the idea of widening of the student's own horizon and repertoire of action as a researcher through dialogues across different perspectives and understandings of the world. Against this background we provide a brief synopsis of course contents with reference to some cases of how students have engaged in it. In order to provide an outlook of further developing this type of reflective space at the University of Luxembourg and elsewhere, the merits and limitations of the approach to date are critically discussed as a basis for formulating some insights and recommendations for future improvements.

MUTUAL REINFORCEMENT OF THE PEDAGOGIC FRAMEWORK AND THE LEARNING ENVIRONMENT

In many, if not most, research universities technical rationality, an epistemology derived from a positivist philosophy (Shils, 1978), prevails. Knowledge in these epistemologies is often treated as a matter of representations of a reality that is pre-existing, and "rule-governed inquiry" is a quality attribute. Generalised abstract propositions then dictate problem framings, data gathering, inference and hypothesis testing. Learning is then understood to be a matter of acquiring the knowledge of these re-presentations. It has been strongly argued that this conception of knowledge, inhibiting criticism and blocking the path to wisdom, is a part of the problem of our failure to achieve sustainability (Maxwell, 2021). An administrative approach to the solution, fully utilising information technology, has already been suggested (Costanza et al., 2021). In this course we explore conceptual elements of a possible solution. One central question of our investigation is how under conditions of complexity it is impossible to divide knowledge from reality as if mind was separated from the world (Fenwick et al., 2011).

The number of sustainability programmes at universities, most of which aim to equip student for dealing with complexity and the diversity of approaches, is increasing (e.g., König and Budwig, 2016). In Italy, for instance, a new law requires a mandatory interdisciplinary course at all universities, modelled on the interdisciplinary concept of sustainability (Fioramonti et al., 2021).

One of the most cited competence frameworks for engaging on sustainability challenges in higher education directs attention to a set of six core and interlinked competences that students should acquire: systems thinking including reflections on boundaries and blindspots; values thinking and interpersonal competences, including in relation to the need of changing social norms, networks and power structures; futures thinking including strategic thinking and embracing uncertainties; and integrated problem solving that often relies on transdisciplinary research that draws on social and natural sciences and is embedded in practice (Wiek et al., 2011, recently amended by Brundiers et al., 2021). The results of Brundiers 2021 Delphi study with experts suggested to expand this list with an emphasis on the need for transgressive learning to unlock path dependencies and dismantle power structures that prohibit required change. Furthermore, the need for capacity-building for action research and transdisciplinary research was highlighted. Other scholars often respond by shifting the emphasis to other, arguably less instrumental aspects, including "an affinity for life and appreciation of diverse life forms;" wise decision making; the ability to question, critique, transgress and disrupt hegemony and routines; unlocking creativity and appreciating chaos, and learning to be and to care, and engaging in non-conceptual states of mind (Sterling, 2013; Barth, 2015; Wals, 2015; Glasser and Hirsh, 2016; König and Budwig, 2016, p. 129; Sterling et al., 2017).

The course described in this paper for early career researchers fills a gap in that whilst a large number of initiatives even in higher education and research universities highlight the need for interdisciplinary approaches for "knowledge integration" for addressing complex sustainability challenges, the issue of knowledge integration is rarely unpacked any further. This course provides an entry point and relevant wisdom from history and philosophy and sociology of science and science and technology studies to discuss challenges to identify and work with different assumptions about our world, and the associated issue that different sets of methods and tools each of which have their limitations and constraints, and the vexing issue of contingency in science.

Therefore, a competence framework for responsible research and innovation that emerged from the EU-funded EnRRICH project is at least as relevant as sustainability competence frameworks (Tassone and Eppink, 2016). This framework shows an important overlap to the above sustainability-related competences by referring to the main competencies of anticipation for future-oriented proactive engagement: a reflexivity that includes situational awareness; inclusiveness and inter-cultural communication as required for participatory research; and responsiveness to navigate complexity or wickedness. Arguably, one of the most fundamental and cross cutting philosophical aims these competences are rooted in is the ability to engage with disparate sets of conceptual constructs that reflect different understandings of constituents of our world and how they might interact (ontologies) and sets of methodologies to study this (epistemologies). This ability is grounded in a researcher's critical and reflexive awareness of their own (disciplinary) assumptions and constraints.

Core assumptions of this course concerning knowledge, science and learning, are that knowledge arises as we engage with the world (building on John Dewey, 1938; Osberg and Biesta, 2007; Wals and Peters, 2018). Accordingly, scientific inquiry is a planned, systematic, structured, self-critical process to create new knowledge that relies on iterative learning processes from action and reflection in practice. Current definitions of action research are closely aligned with this pragmatic understanding of scientific inquiry (see e.g., Reaso and Bradbury, 2008, pp. 4–5). Science can serve to manage but not represent realities. For Dewey education builds the capacity to frame purposes, to judge wisely, and to evaluate desires by their consequences, which will result from acting upon them. There is no greater defect in traditional education than its failure to secure active cooperation of the pupil in construction of the purpose involved in his studying.

The main learning outcomes we want to foster in this course are therefore as follows (**Figure 1**):

Acknowledging values and contradictions in research:

a. A clear understanding of how different disciplines convey different ontologies along with different understandings of what science is and what role it might play in society.
b. The capacity to reflexively and self-critically engage in one's own research choices (concepts and assumptions, methods, substance) in relation to other research paradigms.

Disciplining complexity:

c. The capacity to engage in critical research on complex societal challenges with researchers from other disciplines in a team.
d. An enhanced understanding and repertoire of action in the face of contemporary challenges to disciplined science with respect to complexity, uncertainty, contingency, contradictions, in the face of open futures.

Dependencies on methods and tools:

e. The ability to communicate disciplinary depth across disciplinary boundaries in the awareness of disparate understandings of the world that can be mediated with different methods and tools. This includes the ability to hold a constructive conversation on contradictory facets of specific problems that can be revealed with different methods and tools that are associated with different disciplines.

Allowing for contingency:

f. An acute awareness of limits of generalisations across places and circumstances.

On open futures:

g. The ability to embrace and make explicit a wide range of dimensions of uncertainties and ignorance in relation to one's own and other's research in a constructive manner.

The pedagogic approach relies on staging such genuine dialogues between participants with different understandings of the world by creating a shared space in which participants can learn from each other how they think, and analyse the world in different ways (Mercer, 2000). Rooted in Vygotsky understanding of learning 1962, this implies active and open-minded listening and being prepared to question one's own assumptions and conceptions if there is dissonance or contradiction between diverse understandings (Mercer, 2019, p. 368). Through participation in such a process, learners can experience how knowledge may be constructed and validated (Wegerif and Major, 2019, pp. 113–114). Such a dialogic space that contains (and sustains) perspectives from a diversity of theories and methods including the natural, social and practice-based sciences and humanities that react with each other fosters a *critical interdisciplinarity* that can according to Boix-Mansilla (2010):

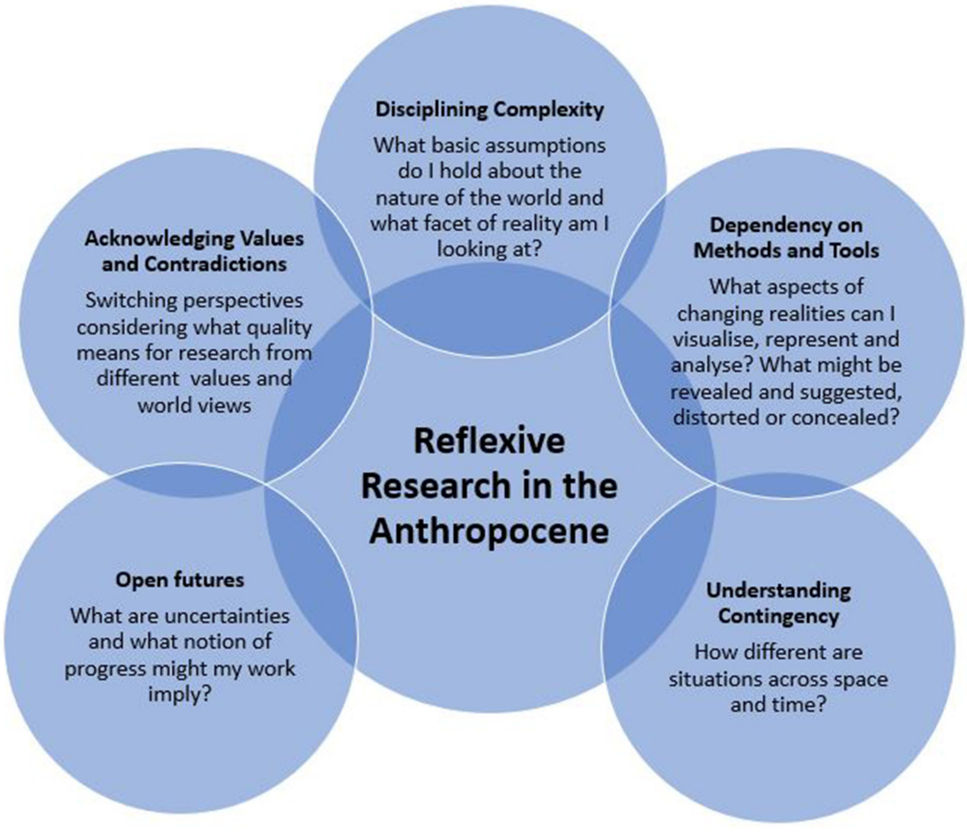

FIGURE 1 | Pedagogic framework of competences for reflexive research in pluralist societies. Scaffolding questions for participants to reflect on their research relating to each competence field: **Acknowledging values and contradictions:** What are the underlying assumptions about the nature of science/knowledge—and the role of the researcher in producing it? To what extent are you/ can you be "objective"? What is the overarching societal question you are interested in and your personal motivation/reasons/rationale for engaging with it? Do you know of others who might not agree and why? **Disciplining complexity**: Which facet of complex phenomena does my chosen discipline direct attention at? How might it relate to other facets/fields of knowledge? What is the main chosen discipline/research area and what are your core theories and concepts? What makes your field of research different from others? Why have you chosen it? What are your 3–5 main research questions? Please state your field's underlying assumptions about the nature of actors, agency, system, and the relation between actors and the system, or the conception of the ability of actors to contribute to systemic change? **Dependencies on methods and tools**: What is your research methodology? Are you tri-angulating insights from several research methods? Which facets do your theoretical and methodological choices highlight, suggest, reveal? Which blind spots might you produce? What aspects might you distort or conceal with your methodological choices? **Understanding contingency**: In how far do you engage with abstract situations and concepts and models and with how many different situations do you test these? **Open futures**: What is the relation between your research and "progress?"

- help to overcome limiting assumptions and pre-suppositions;
- make explicit divergent preferences and priorities and their value bases that are united in their orientation to co-create more sustainable futures;
- serve as a basis for processes to critique, judge and evaluate new knowledge emerging from such processes from diverse points of view; and
- foster empathy, humility, reflection required when directing attention to people, roles and relationships in place- and issue-based analysis.

The pedagogic tools and activities to scaffold participants reflections on their own research, motivations, and justification of choices of concepts, methods and substance, and to link these to materials in each course session we developed for this course bear some similarity to those developed by Kemp and Nurius (2015) to equip students for transdisciplinary research. These include opportunities to reflect on personal knowledge frameworks and their origin in one's own personal experiences, including in future by developing an intellectual biography and a set of scaffolding questions similar to the tool box dialogue method by Eigenbrode et al. (2007) (see caption of **Figure 1**). The tasks include to summarise and engage in debate on philosophical texts across different ontological backgrounds; present research react to others research. The participants and the convener jointly develop the plan for the course—who chooses to present their research in order to best match the philosophical contents of the sessions with the contents of the research projects and the interests of the participants. Participants are asked to complete a final reflective report relating materials and debates covered in all sessions to general insights they gained as well as reflect on implications for their own research.

In terms of learning environments, the University of Luxembourg, founded in 2003, is extremely suitable as it offers diversity not only across disciplinary, but also cultural, backgrounds. It is tri-lingual, has an international orientation with students from 130 countries, and is close to several key EU institutions. The highly international and therefore also multi-cultural nature of the University has exchange agreements and research cooperation with more than 100 universities worldwide, and cross-border study and research is commonplace. It has three faculties (broadly divided between social sciences and the humanities, natural science and engineering, and economics and law), and furthermore three interdisciplinary centers. The university rectorate runs transversal skills training courses for doctoral researchers from all faculties. The course presented in this paper is part of the transversal skills training. This is significant given that the presented approach to learning relies on participants with very different understandings (even ontologies) engaging in dialogue with each other. While originally (since 2014), run as part of one of the doctoral schools within the faculty of social sciences, as of 2020 it is offered as a cross-faculty course. The setting also guarantees a diverse cultural field—in 2020 ten participants came from four continents.

COURSE CONTENTS, STRUCTURE, AND DISCUSSIONS

The course is structured in accordance with the pedagogic framework of **Figure 1** in five sessions of 3 h each and invites a maximum of 10 participants that approximately correspond to the five competence fields in the framework. One or two doctoral research projects are selected for presentation at each session and all participants are asked to summarise one to two readings at the start of each session and to discuss the readings and main insights gained with each other.

1. What is a discipline purpose of science and received framings—challenges to science from **complexity and contradictions** in the face of complex sustainability challenges relating to human environment interactions
2. **Methods and tools**, uncertainties and the role of science in paradigm shifts
3. **Contingency and instrumental interdisciplinarity**
4. **Values and interpersonal competency**
5. **Futures and dynamics—accelerating change**

This results section covers what the authors consider the essence of the core readings recommended on the topics of each session. Three case studies of how participants' research projects have been related to a session topic are presented.

SESSION 1. ON THE EMERGENCE OF DISCIPLINES AND THE CHALLENGE OF COMPLEXITY

The introductory session serves to critically discuss what science is and what science does. Participants introduce their research, trying to relate their research approach in informal conversation to those perspectives that resonate most with them.

A simplified overview on the evolution of the disciplines building on a synthetic chapter by Peter Weingart (2010), serves the course introduction extremely well. In the nineteenth and twentieth century, rapid growth of data sets resulted in pressure to treat data selectively according to criteria specific to science. The constitution of problems of study increasingly took its point of departure from abstract concepts and methods, rather than from place-based practical questions or interests. Experiences were no longer grasped but constructed, research laboratories with controlled environments were devised for inquiry. A growing stock of concepts, theories, and instruments allowed expanding this new scientific mode of knowing to new subject matters. Increasing specialization both gave rise to more enclosed "communities of practice" within different knowledge fields, in which "relevance" is constructed by peers (e.g., in specialised journals). The pressure to discover something original and novel became a disincentive to cycle through diverse disciplines, but to remain within one field—specialization through division of labour leading to the increasing fragmentation of knowledge fields and difficulties to communicate across these (see also Kuhn, 1962). Concerns about specialization and fragmentation arose already with the emergence of the disciplines: "a thousand busy ants are producing daily countless details… only concerned to attract attention for a moment to obtain the best price for their goods," the stream of discovery is split into ever more and ever more unimportant trickles (Du Bois-Reymond, 1886, p. 450).

A discipline today can be seen to comprise the following elements: A complex of problems—that presents a delineated subject area with associated sets of permissible questions; Shared concepts, methods and instrumentation; A social community with identity, quality criteria and membership rules they adhere to.

Different disciplines convey different ontologies, as highlighted by Thomas Kuhn (1962), who takes issue with the dogmatic way that many disciplines are taught at Universities tightly defining permissible sets of questions and tools for inquiry. Peer review and career incentives usually suppress divergent questions that are not within a field's frame. This can further exacerbate the fragmentation of knowledge, and entrenching disparate fields of knowledge with divergent ontologies and accordingly different criteria for legitimating new knowledge.

In the natural sciences instrumentalist or positivist view often prevails. Today some scholars distinguish between three and five fundamentally different ontologies that can be associated with different knowledge fields in the natural sciences, social sciences or humanities (**Table 1**), including positivism, social constructivism, and pragmatism's belief in participative, experiential and emergent realities, each of which attributes science a different role in society (e.g., Heron and Reason, 1997). In our pluralist societies, the practice of science needs to acknowledge and embrace the possibility of ontological pluralism (Wals and Peters, 2018), whilst continuing to assure legitimacy of the knowledge produced within single disciplines rooted in explicit and self-referential ontological systems.

TABLE 1 | Simplified views associated with different ways of practicing science.

	Logical positivist	Social constructivist	Experiential/emergent
Purpose	Scientific practice allows to discover truths in the real world. It largely serves to understand the world's components and cause-effect relations between them.	Science is a social institution that produces knowledge and technologies, which reflect and reinforce prevailing values and power structures.	Science structures inquiry and allows learning. Inquiry relies on interaction in practice and reflection.
Science and Situation	We can discover universally applicable laws that apply to natural phenomena across different situations.	Science is culturally conditioned and depends on language. Scientific concepts are in the imaginary realm, no single definition of truth. Speech-act theory asserts the role of language in change.	Practiced in a world of contingency, complexity and contradiction. Subjectivity of the researcher, personal experience, intentionality and normativity are all relevant and should be reflected upon.
Methods	All knowledge is based on data of experience and can be scientifically verified.	Methods such as discourse analysis can help the interpretative scientist to identify prevailing patterns of thought as well as marginalized voices.	Scientific method comprises formulating hypotheses, testing in action, observation and reflection cycles in practice, assuming non-linear causality.
Prevalence	This view prevails in the natural sciences, and in society at large.	This view prevails in the interpretative sciences and in some intellectual circles concerned with equity.	Increasingly prevalent view as addressing complexity and interdependencies is seen as necessary for survival.
Roots	Aguste Comte, Rudolf Carnap, Gustav Bergmann. Karl Popper's description of the empirical method, and reasoned, logical attempts of verification and falsification.	Searly, Austin, Jacques Derrida, Michel Focault, Pierre Bourideux. Thomas Kuhn's description of science as a social institution with strong gate keepers.	American pragmatism, systems theory, etc. Philosophers of science and cognition, as well as cognitive psychologists with an interactionalist stance on knowledge.

SESSION 2. THE ROLE OF TOOLS AND REPRESENTATIONS IN SHAPING OR BREACHING PARADIGMS

This session serves to explore the question of the extent to which methods, tools and representations shape bodies of knowledge in disciplines—what aspects of reality are revealed or suggested, which may be distorted or concealed? Does the reliance on a specific set of tools promote or hinder breaches in paradigms?

The long evolution of humanity has been marked by the creation of ever more powerful tools that help us to develop representations of states and processes that are not directly amenable to detection with our senses because of issues of scale, distance or the level of abstraction. Modern science was born with the creation of special instruments for exploring Nature: telescope, microscope, air-pump, and mathematical techniques like decimal fractions and logarithms (Shapin and Schaffer, 1985). Now tools are often the focus of the scientific endeavour, like the particle accelerators at CERN or continental-scale radio telescopes. Normal science depends on a stock of standard tools, which can be so sophisticated as to require special expertise for their use, such as mathematical methods like statistics, computer simulation models and big-data. Then there arise social problems and conflicts between tool-users and tool-providers (Ravetz, 1971). Issues of competence and integrity are also encountered. Because tools cannot be tested like scientific claims (they may be inappropriate but never simply "wrong"), controlling their quality is even less straightforward (Ravetz, 2003). The crisis of "irreproducibility" in many research fields is partly a result of widespread misuse or abuse of mathematical tools (Bishop, 2019).

Another set of problems arises from those tools that represent objects and not merely manipulate them. This is most easily seen in connection with statistics, where the mean of a data-set, or even its variance, tend to be treated as just another objectively given data point. In the sciences of complex systems, measurable processes that serve as proxies for their underlying causes are again prone to be taken as the real causes. There is no easy cure for such systematic misinterpretation of the empirical basis of science; awareness and criticism are the only protection against the error and vacuity that can result from misunderstood tools and representations.

One case study on tools and representations was based on the discussion of a PhD project on the fundamental properties of light-matter interactions by Ricardo Rojas-Aedo. The research sets out to reconcile formerly apparent contradictions between semi-classical and purely quantum physical interpretations thanks to the sustained development of technologies associated with ultrashort pulsed lasers. The temporal resolution achieved with these lasers makes it possible to study the interaction of materials with the wavy electromagnetic fields that make up light as a series of consecutive ultrashort constant fields, in a limit where the quantum concept of photons becomes meaningless. This approach therefore allows to open questions about the partly contradictory assumptions of classical physics and quantum mechanics and the nature of the study process itself.

SESSION 3. INSTRUMENTAL SCIENCE AND INTERDISCIPLINARITY: THE DILEMMA OF RIGOR OR RELEVANCE

This session is concerned with the tension between abstract "textbook science" and situated knowledge and the role of instrumental research that helps to relate insights from diverse disciplines to each other in relation to a practical problem (Krohn, 2010). The term "applied science" reflects a conception that presents practical tasks as derivative, merely making use of some knowledge that is handed down by its creators.

Schön (1983) describes the nature of this complementarity and its relation to problem solving in practice by distinguishing the high ground of research-based theory and technique and the indeterminate swampy lowland of messy realities in open unpredictable systems with confusing ever-changing problems that defy any clean rule-based technical solution, let alone adhere to the strict boundaries between the canons of the disciplines. Both professionals and researchers thus face the "rigor vs relevance" dilemma, exacerbated by unfortunate associations of more "prestige" to the latter. Moreover, already in the 1980s some scholars (Rein and White, 1980) not only noticed the separation of research and practice in many knowledge fields but that research has often been captured by its own agenda.

The need for science to embrace interdisciplinarity for increased salience and for adequate lenses of analysis and action repertoires is discussed by Gibbons et al. (1994), Nowotny et al. (2003), and Krohn (2010). Boix-Mansilla (2010) notes that while interdisciplinarity features prominently on mission statements of universities are research proposals, cognitive processes central to interdisciplinary integration are not fully understood.

A case study on Educational sciences and practice by Bo Raber demonstrated a design-based research approach (Bakker, 2018) to develop learning materials for collaborative conceptual systems mapping in relation to practical sustainability challenges (similar to Newell and Proust, 2018) in diverse school settings. This iterative design process with empirical testing allows relevance to be constructed in collaborative approaches that involve researchers and practitioners—including in this case teachers and pupils—because the resulting methods design and the transfer guidelines are the product of a "reflective conversation with the situation" (Schön, 1983).

SESSION 4. SCIENCE IN SOCIETY: EMBRACING COMPLEXITY, CONTRADICTIONS AND VALUES IN RESPONSIBLE RESEARCH DESIGN

This session explores the urgent current challenges to the maintenance of quality in science. One main challenges is that the activity of research is now embedded in a more complex and dynamic context than can be captured by our inherited notions of traditional research approaches within the disciplines. Moreover, societies are increasingly pluralist with different groups defending different sets of values and understandings of the world. Questions for discussions include "what new quality criteria might look like, which better take account of the complex and dynamic social, environmental and technological context that research is embedded in?" Subsequently the session discusses "How can the design of research be brought up to date in view of these new requirements to quality control?"

For the effective conduct of science, the traditional scientific ideal of "Truth" is to be enhanced with Quality (a complex idea), Integrity (in the face of corrupting pressures), and Responsibility (to society and Nature) in science. Roots of social norms of science (Merton, 1973) and the social contract of science (Guston, 2000) are explored. The concepts of quality, and quality assurance, are familiar to most, yet what contributes to quality will depend on the subject, the people involved, and the items being compared. It is a complex idea, with aspects that are pragmatic, technical and ethical. Attempts to systematically define quality according to standards (e.g., ISO 10005), have often resulted in the evaluation of administrative characteristics ("box-ticking") (Gill et al., 2010). These authors argue that the ill-defined nature of quality is something that should be embraced, as it enables all concerned parties to participate in discussion regarding its meaning and relevance to the particular case.

In science, the most common tool for quality assurance is that of peer review. This process makes science almost unique, with the assessment performed by accredited practitioners rather than by users or external critics (Funtowicz and Ravetz, 2015). While internal peer review is likely to detect major errors and fraud, critics point out the process can be inconsistent, biased, and abused (e.g., Wennerås and Wold, 1997; Smith, 2006). Critics of the current disciplinary peer review process do not propose to remove it altogether, but argue for its expansion (Funtowicz and Ravetz, 1992). This is proposed not to cross boundaries between scientific disciplines, but to allow for proper public scrutiny. With the continued loss of public trust in science, there have been persistent calls for greater connectivity between science and society (Wals and Peters, 2018), urging science to become a more open and democratic activity welcoming public engagement.

Reframing conceptions of science in view of these challenges include developments of the concept of "Post Normal Science" (PNS) (Funtowicz and Ravetz, 1993), citizen science and transformative sustainability science. Post normal science is focused on demonstrating the inadequacies of the inherited sense of science by invoking the supremely uncomfortable proclamation "facts uncertain, values in dispute." It emphasises quality (a complex attribute!) in the form of extended peer review of a community that is touched by consequences of the research as the touchstone of genuine science. In some forms of citizen science, citizen volunteers engage not only in collecting data but also in framing the research questions, choosing methods and defining acceptable evidence, this can also help the consideration of local contingencies in international research projects (Shirk et al., 2012; Haklay, 2015). Similarly, transformative sustainability science can include transdisciplinary approaches in which research is on tap and practice is on top in a similar manner (Schneidewind and Singer-Brodowski, 2013; Wiek and Lang, 2015; Grunwald, 2016; König, 2018). Such collaborative research practices suggest a shift from appropriating citizens' contributions as in "research as mining," to "research as co-learning" and "research as activism" rooted in socially critical transformative and transgressive traditions (Dillon and Wals, 2006; Wals and Peters, 2018).

Thus even when participatory research is not an option within a discipline, we do encourage researchers to view their projects not as stand-alone problems, but to consider them in the framework of dynamic systems, which in addition to scientific and technological components also include the social and ecological. Ensuring that the quality of the project can be judged not just by a select few peers, but by the wider audience, will require considering the complexities arising through the dynamics of such systems, and addressing apparent contradictions as seen from various viewpoints, within them. Especially the question of framing and purpose of research deserve considerations of other groups than just epistemic groups.

A case study on citizen science for sustainable water governance by Karl Pickar explored the potential of citizen science as an approach to scientific inquiry that fosters stakeholder engagement, social learning and as well as more detailed, place-based and diversified data collection to allow a better understanding of the contingency of environmental problems and design of more locally adapted measures. Challenges of engaging non-experts in scientific research and implications for the notion of "quality" in science can be explored based on such examples.

SESSION 5. SCIENCE AND PROGRESS IN THE FACE OF EXISTENTIAL CHALLENGES

This session serves to create discussions of diverse understandings of the relation of science, technology, intention, action and progress and human futures. Thomas Kuhn in his book on the structure of scientific revolutions challenged the assumptions of the cumulative nature of science. In his scheme, cumulative progress occurs only in "normal science," the puzzle-solving activity of articulating an unquestioned paradigm; really just one step on from the textbook exercises on which students are trained. Real, revolutionary progress can happen only when this routine puzzle-solving doesn't work, in the discoveries of "anomalies" that can't be resolved, for instance if Nature itself makes prior scientific achievements seem problematic. Progress in that sense may thus an evolution not of how much we know, but of what we wish to know.

In America, the focus was on practice, and the leading philosophers called themselves "pragmatists." For them, the (never-ending) search for Truth in science was less important than its usefulness. Their two most influential thinkers were also distinguished scientists outside the traditional theoretical group; William James was a psychologist and John Dewey an educationalist. For them, Knowledge is the foundation for beliefs that guide us to get what we need and want. All knowledge is justified to audiences, and knowledge can thus be equated with "justified belief." The quest for certainty should be replaced with a demand for imagination, for a better world, including for example changes required for more just and equitable democracies. According to John Dewey we should also ask ourselves whether we are asking the right questions of which aspects of our understanding of the world may need to change, in order to serve us better.

Interdisciplinary research approaches exploring the relation between science, knowledge, technology and prevailing social norms, structure and practices have developed helpful heuristics to explore such questions. For example, Socio-technical Imaginaries (STIs) are 'collectively held, institutionally stabilised, and publicly performed visions of desirable futures, animated by shared understanding of social life and social order attainable through, and supportive of, advances in science and technology (Jasanoff and Kim, 2015). STIs cut through the binary way of thinking in terms of agency and structures by focussing on the nature of their relationship and the hybridity of the term opens windows on co-produced realities.

But how can we learn to approach the future as open, with or without resorting to more structured modes of scientific inquiry, rather than simply an extrapolation from our present views and needs? A promising tool is scenario development, where participants are confronted with diverse and possibly contradictory perspectives (Swart et al., 2004; Ramirez and Wilkinson, 2016; Drenth et al., 2018). More recent transdisciplinary research on alternative futures relating to sustainability challenges clearly confirms that approaches such as participatory processes to develop sets of scenarios can serve as a frame for participants to consider futures as open. They can then escape from just arguing from their own experience, when confronted with diverse and possibly contradictory perspectives (Swart et al., 2004; Ramirez and Wilkinson, 2016; Drenth et al., 2018). Moreover, scenario approaches also have the potential to build competences strongly associated with sustainability, including the capacity to take part in *systemic sustainability dialogues* a that foster a participatory creation of systemic knowledge and coping strategies in "wicked problem" situations. It accomplishes this by applying systems thinking in the development of scenario narratives, thereby recognizing interdependencies, and anticipating different futures and pathways.

CONCLUSIONS ON PRACTICAL IMPLICATIONS AND LESSONS LEARNED

In sum, the ambition of this doctoral school course is to open a space for critical reflection on one's own research in order to reframe merits and limitations of the approach through dialogue with others who have an entirely different ontological understanding of the world (with different basic assumptions of what elements the world is made of, and how they interact). Learning often happens by challenging boundaries of (material and social) learning environments (Brown et al., 1989), thus the cross-faculty setup is particularly important for its success. Learners—including teachers along with students—need to be challenged by the experiences and perceptions of others in a dialectical manner. Embracing complexity, conflict, uncertainty and ignorance starts with the acknowledgement of plural rationalities and contradictory behaviors that can be discovered to be useful resources within diverse groups, organizations or networks.

Quality attributes of this course can thus be seen to include the diversity of understandings from a diversity of theories and methods, including the natural, social and practice-based sciences and humanities. Evaluation of learning in the course is qualitative and is based the competence fields of the pedagogic framework in **Figure 1**. This section presents a synthesis of observations from class discussions in 4 years of running the course, analysis of the final reports participants submitted in which they synthesise main insights gained from the readings and class discussions for each session and for the course as a whole in relation to their PhD research, short evaluative conversations with participants after completion, feedback on the course by students received in e-mails, as well as statements made in a short feedback survey questionnaire that was administered electronically after the most recent edition that ran from March to May 2020.

Main lessons learnt in the course relating to the competences for reflexive research depicted in **Figure 1** include:

1. **Acknowledging values and contradictions in research:**

Several students were also surprised at the wide range of understandings of roles of researchers and quasi contradictory meanings of responsibility depending on which field of research you are engaged in.

Challenges of communication across different disciplines were discovered to be unexpectedly challenging: Absence of "common languages" (indeed, "fragmentation is huge!"), barriers to dialogues: course was an eye-opener in terms of how "entrenched" everyone (incl. myself) is in their own terminologies and concepts (even within same disciplines!)—how difficult it is to explain own research to others—and to be able to understand and relate to other research (confirming increasing difficulties in peer review)—how can science contribute to societal debates and processes, if researchers among themselves have problems in having dialogues about what they do, how and why?

> *"It was fascinating to see how difficult it actually was to generate understanding across researchers from different faculties, when talking about our Ph.D. projects! Many of us did not really manage, and only got questions on our research once the facilitator paraphrased and reiterated somethings we said in different terms and with different questions."*
> *"Challenges of Transdisciplinary Research Design were clearly highlighted to me in the seminar in terms of ongoing exchanges with societal actors to ensure saliency and "validity", notably via feedback on interpretations, results – scientific "quality" then possibly also emerging from "being close to society/actors", including experiments with methods, while ensuring some coherence and consistency."*

From the very cross-cultural setting of the University of Luxembourg the organisers noted with surprise how consistently participants from Latin American universities, the continent of Paulo Freire, excel in reflexivity and have a concern for justice. Western science was more than once associated with colonialism, past and present. And they have been taught similar courses and have substantial acquaintance with theories of knowledge regardless of their subject of study—be it theoretical physics or social sciences. The theory of Post-Normal Science is becoming well established there; this provides a basis for the critical awareness of science that this course attempts to foster (Giatti, 2019).

2. **Disciplining complexity?**

Several participants noted on the surprise that upon closer reflection the purpose of research is not self-evident, but itself contested, especially if viewed from another discipline and field. Discussions clearly highlighted some of the merits and limitations of, respectively, transformative research (challenge-driven, practice-oriented—never neutral, openly normative, quality standards are tricky) and "positivist" science (belief in objectivity, clear fixed quality standards, but rarely reflexive). Participants appreciated hearing how other fields of science see their role in society and how they choose research questions. Illuminating questions were: what is deemed necessary, what is a good question in the light of the existing paradigm, what is ignored, and which questions are deliberately left unasked.

> "*The main insight for me was to see how deep fragmentation runs in sciences, how very difficult it is to actually have dialogues between different scientists, how difficult it is for everyone to make own assumptions explicit and to question them, see problems from different perspectives, how much more reflexivity and spaces for dialogues are required to actually be able to practise interdisciplinary (how little reflexive researchers are in general about their own research and discipline/field), how important reflexivity is! A huge challenge for universities and researchers!"*

3. **Dependency on methods and tools**

Statements by participants noted that it was very enlightening to inquire into how scientific knowledge has been "shaped" by the invention of specific technologies, and vice versa, and gone hand-in-hand with wider societal developments—how science, technologies, society have "co-produced" (STS) each other—thus seeing own research as part of wider human-environment-technology systems, and as inevitably "situated"

> *"This … brought me to reflecting seriously about quality and saliency (for societal challenges) how they can be "achieved" through approaches such as the triangulation of methods."*
> *"The importance of openly addressing ambiguities, blind spot, etc. of own research is now clear."*

4. **Understanding contingency**

Further, the course was appreciated by several participants to provide perspective and the structural reasons for "the fate of their research projects." These were in terms of initial hopes and aspirations to shed light on vexing societal problems that often get truncated to fit into the tight shoe of a discipline…

> *"It was interesting to me to see the difference between investing effort in definitions versus investing efforts in understanding—where real understanding often was only achieved in relation to a specific situation."*

5. **Open futures**

It is also clear that some topics were more successfully and in depth assimilated than others. No participants ventured forth to discuss the relation of their research to understandings of progress and open futures and uncertainties. Accordingly, we will revise readings and approach to this pandora's box and reflect how to scaffold this part of the course in a more reassuring way. In the end it is also about building emotional certainty in the face of uncertainty and making this goal more explicit. The last year teaching in the virtual realm during the pandemic was certainly not conducive towards achieving this—learning in this domain will likely largely depend on the quality of relation between peers and the mentor such that the course is perceived as a safe space.

More general feedback also on matters of practical implementation included that the volume of assigned reading was too high. There were also a large number of general positive statements two of which that are deemed representative of many voices are included below.

> "*(It) was the only opportunity offered throughout my PhD to truly critically reflect on my research, and about what an engagement of 'producing knowledge with scientific methods' may actually mean for myself as a researcher and for society at large.*"
> "*This course was one of the most satisfying, challenging, and fulfilling I've ever participated in.*"

Implications for Organization of the Course in Future and Adaptive Trials in Diverse Settings

- Explicitly invite participants to present their research in "lay language" to others—explaining why the research is (potentially) important for society, their own purposes they pursue (motivation), as a basis for dialogues (including "extended peer communities)."
- Include reflections on the history of their own discipline/field (origins, mission, core understandings) and how their thesis relates to that history (might be a way to get to underlying assumptions, which can be very difficult).
- Add one assignment initially for participants to develop a personal intellectual development path that brought them to their current research topic, questions and approach. As suggested in Kemp and Nurius (2015).
- We will in future based on this analysis hold a scenario workshop in which participants are invited to describe perceived salience of intentions and quality of expected outcomes in three different scenario worlds developed as part of other research projects of our team in Luxembourg.
- In particular the one course run during the Covid-19 related Lock down that was confined to dialogues in the virtual realm showed that digital dialogues might need more/different scaffolding opportunities for participants to truly engage with what they say about each other's research, and not only what is said about shared literature, or what the convener of the course says.
- More opportunities to meet each other as people also in different contexts (go for a drink!) as well as researchers and get to know the cultural diversity as well as the scientific disciplines.

It should also be noted that the course considers transformative learning to be a life-long iterative process (Sterling, 2004), doors which may be opened through collaborative engagement in projects that integrate education, diverse research paradigms and civic engagement (Gough and Scott, 2007). In the five sessions, these doors cannot be opened, but at least can be made visible and explicit.

Furthermore, the goal is to equip researchers and in a next step, to invite them to return back to their respective research groups and present these debates within their closed circles of peers to act as change agents and multipliers across faculties and research groups in universities who choose to institute this course. Critical analysis of participant's research projects serves as the basis to clarify how disciplined research approaches may simultaneously reveal, suggest, distort and conceal different facets of realities by focusing on particular systems, scales of analysis, fineness of perception, and time spans. Ultimately, the goal would be to get all research groups across the university to explore jointly with their doctoral researchers the dependence of knowledge fields on their respective methods and tools, as well as on their conceptual foundations and prevailing assumptions.

In sum, these foundations equip one to reflect more competently on the merits and limitations of one's own research, and its relation to its social contract and ethics. Such reflexivity and dialogues across specialised fields may enable a more critical approach to disciplinary assumptions, and a better understanding of the challenges of truly interdisciplinary, or even transdisciplinary, research design. This reflexivity is required to address more complex societal challenges, and to reflect on the quality attributes within diverse fields of research in the turbulent times of the twenty-first century.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

AK wrote the manuscript while incorporating the individual contributions. JR helped develop the framework covered by the course, assisted with writing the manuscript, in particular the Introduction and Sessions 2 and 5. BR assisted with writing the manuscript, in particular the example of his own research and the pedagogical framework and principles. JS assisted with the course organization, and for the purpose of the manuscript with discussing Sessions 3 and 4 and general manuscript preparation. RR-A assisted with proof-reading the manuscript. KH assisted with formulating the discussion section. KP prepared the example based on his own research, assisted with proof-reading the manuscript.

All authors contributed to the article and approved the submitted version.

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