Chapter 1
Creative Pragmatics for Active Learning in STEM Education

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1.1 Models for Knowing

We start with a big question. Is the world knowable? Much traditional education rests on the idea that this is the case: the world is finitely knowable and we can transmit positive knowledge of it. "Knowledge is the thing" (Pickering, 2010 p. 390). We challenge this conventional view of knowability, urging that we embrace the complex and dynamic nature of knowledge creation and its inherent uncertainties. Although questioning the stability and completeness of knowledge may feel uncomfortable, we suggest that it is important to endure the discomfort, in order to consider the implications for education, of a world which is not finitely knowable.

We argue that it is time for science, technology, engineering and mathematics (STEM) education to help learners, not only to master the laws of nature but also learn to navigate the dynamic realities of exceedingly complex systems and their unpredictable interrelations.

This book highlights creative agency, suggests that education could and should play a pivotal role in purposefully redesigning our actions in the world, and underscores that science and technology, as forces shaping society, can be reconfigured to better serve humanity and our companion species.

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C. Svabo et al. (eds.), *Creative Pragmatics for Active Learning in STEM Education*, Contributions from Science Education Research 14,
https://doi.org/10.1007/978-3-031-78720-1_1

> The university ought to take an active role in planning society, and in particular, in the planning of science and technology in the service of society. (p. 102)

> We will need a type of education which fosters judgement in complex and dynamically changing situations. (p. 102)

> The task is nothing less than to build a new society and new institutions for it. (p. 101)

These forward-thinking calls come from Erich Jantsch's, 1972 essay in an OECD document about the need to be interdisciplinary and more, to be transdisciplinary. They are still highly relevant today.

If there is only one takeaway for the reader from this book, it should be this: there is no solid ground of science for science education to stand on. Science and technology can reconfigure and can be reconfigured. Science, as traditionally taught, often emphasises predictability, stability, causality, and reduction. Yet, we inhabit a world that is complex, dynamic, and interdependent—a reality that even extends to natural systems. The traditional view of science as aspiring to objectivity and replicable certainty does not fully account for the complexities and ever-evolving nature of scientific understanding (Gilbert, 2004). While we value the validity, reliability, and generalizability that accounts of science in education offers, we also advocate for a broader perspective that includes truths that are contingent, partial and situated. We emphasise the need to foreground the role of the knower in the known (Davis & Sumara, 2006), recognise the co-agency of instruments and technologies in knowledge creation, and address openly the ecological and existential crises we face (Pickering, 2025).

We are not rejecting science. Far from it. Rather, we advocate an expanded science paradigm informed by complexity thinking, systems thinking, cybernetics, ecology and science and technology studies (STS). This expanded paradigm highlights the interdisciplinary nature of contemporary scientific inquiry. It emphasises transdisciplinarity, a holistic perspective, interconnectedness and interdependence between systems, and focuses on the role of science and technology in shaping society (Bijker & Law, 1994). This also encompasses agential realism, response-ability (Barad, 2003, 2007) and new materialist approaches (Bennett, 2010). This expanded science paradigm transforms how scientific problems are conceptualised and addressed, and can lead to unique research agendas, understandings, and methodologies.

In resonance with this assemblage of interdisciplinary subfields in an expanded science paradigm, we advocate for a science *education* that integrates personal experiences with a principle of human-non-human symmetry, collective practices and global realities.

Our book *Creative Pragmatics for Active Learning in STEM Education* proposes that science education should not only convey established facts but also teach students how to navigate and engage with the shifting and interconnected challenges of the world. Creative Pragmatics is about preparing learners for the future by embracing adaptive and responsive approaches in a science education that is informed by the latest insights from across the scientific disciplines.

By integrating holistic insights from an expanded science paradigm with pragmatism, and art and design, Creative Pragmatics promotes a performative model of knowing, emphasising the active, engaged learning that is essential for handling contemporary scientific and societal challenges. This approach promotes learners to see themselves as agents in the world, not mere spectators, echoing the sentiments of pragmatist philosopher Anne Ruth Putnam (Putnam & Putnam, 2017 p. 111) stating that "the future is not determined; human beings cooperating can make the world better," and—with inspiration from physicist, science and technology scholar, and one of the foreword authors of this book Andrew Pickering—we modify this sentiment for the Anthropocene epoch into the still mildly optimistic statement that the future is not determined; human beings cooperating with the world can make the world better.

In sum, this book aligns STS informed performative models of knowledge with pragmatic educational philosophy to emphasise creative agency in education, connecting skills and competencies with active, engaged learning under the banner of Creative Pragmatics.

1.2 A Holistic Perspective

In the rapidly evolving world of contemporary late modernity, our globalised societies are confronted with the many intricately intertwined and familiar challenges of climate change, biodiversity crisis, migration and displacement, populist autocracy, the persistence of armed conflict, deep-seated societal disparities, and the unforeseen consequences of remarkable scientific development and technological innovation (Peters, 2017; Van Berkel & Manickam, 2020; Svabo, 2021; National Intelligence Council, 2021).

Multiple crises have emerged through the cumulative effects of human activities on the planet. Complex phenomena reveal the limitations of orthodox models of research and knowledge building which hinge on reductionism and predictability.

Simple solutions that treat problems as isolated and controllable are inadequate in this context. Each of these phenomena is multifaceted and consists of interconnected elements, meaning that changing one aspect will inevitably trigger cascading effects throughout larger systems (Byrne & Callaghan, 2022; Sawyer, 2005). The interconnected nature of contemporary challenges requires a holistic perspective that accounts for the complex interactions between various issues. This holistic approach recognises the necessity of integrating diverse disciplines and perspectives to fully understand and address these challenges. This new reality underscores the need for education, research and innovation to develop new competence and new models for knowing.

We have to shift to models for knowing that are open, iterative, systemic, holistic and more-than-representational. We have to shift towards creative and pragmatic agency. This is also a shift from purely representational ways of understanding knowledge towards what Andrew Pickering calls performative models of knowing, underscoring practice and performance (1995, 2010).

Performative models of knowing emphasise the active, dynamic process of engaging with the world, where knowledge is constructed through interaction and practice rather than simply represented. Such models value the role of human creativity working with the world, continuously learning and dealing with new information and challenges. This approach highlights the importance of experimentation, adaptation, and the co-construction of meaning between humans, technologies, and environments, recognising that understanding emerges through doing and experiencing. By embracing performative models, we empower learners and researchers to become active participants in shaping the world, leading to more sustainable situations.

1.3 Learning in a Complex World

Complexity is a central feature of our world and learning organisations and educational institutions need to understand and engage with this (Nicholls, 2018; Gallagher & Savage, 2023). Systems thinking, holistic perspectives, and recognising societies as complex dynamic systems underscore the necessity to understand the concept of emergence.

Studies in complexity offer a radical and innovative frame for understanding the nature of professional practice, particularly away from the idea that professionals, leaders, managers, or other employees are in control. This highlights that we are living in a complex world (Davis & Sumara, 2006; Davis et al., 2008; Svabo, 2021).

Funtowicz and Ravetz's (2018) concept of post-normal science deals with high systems uncertainty and high decision stakes, while normal applied science operates in low systems uncertainty and low decision stakes. The concept of post-normal science addresses epistemic uncertainty, rethinking the nature of science and seeks to democratise science education by including students and teachers as stakeholders (Agustian, 2023). Educational institutions and organisations are confronted daily by continuous changes that motivate them to develop new strategies to respond to the emerging challenges.

The complex issues and heterogeneous and interlocking processes we deal with in contemporary life require skills and competencies to navigate complexity. As such, competencies and a skill set extending beyond conventional content learning or problem-solving is imperative (Wong, 2020; Davis & Sumara, 2006; Davis et al., 2008). Proficiency in critical thinking, creative ideation, and transdisciplinary systems analysis becomes essential.

Creative Pragmatics is a synthetic concept intended to help attend to this necessity. Creative Pragmatics underscores the importance of integrating creativity, critical thinking, problem-solving, communication and emotional intelligence within active STEM learning settings, enabling students to learn to deal with real-world challenges effectively.

1.4 Policy Highlights the Importance of Handling Complexity

Educational policies emphasise the need for knowledge, skills and competencies that allow graduates to navigate and act in complex situations. The importance of developing the capability to act in situations and circumstances of complexity is supported by policy in both the US (National Research Council, 2013) and Europe (European Qualifications Framework, 2017), as well as by global organisations, such as World Economic Forum (2023) and OECD (2019).

Policy highlights the understanding of systems, system modelling, and handling complexity as crucial learning goals. Policy emphasises the need for developing competence to work in complex situations and to communicate with non-experts, as well as the ability to come up with new solutions, to work with ill-defined problems.

The qualifications expected of students in the EU "second cycle qualification framework" are, that students "have the ability to integrate knowledge and handle complexity, and formulate judgments with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgments", and third cycle qualifications expect that students: "are capable of critical analysis, evaluation and synthesis of new and complex ideas." (European Qualifications Framework, 2017).

In such a framework, students are expected to develop competence in handling complex and unpredictable work situations. It is expected that they can assume professional responsibility and with autonomy can initiate and carry out collaboration across disciplines and organisational levels. Students must be able to structure their own work, and the objective is that they develop into self-directed and autonomous individuals. An important component of this is not only to be reactive to externally motivated goals, but also to be able to formulate goals, interests and concerns in self-directed ways and to assess and make informed decisions based on incomplete information and in situations of insecurity, change and risk. This makes it necessary to develop creative competencies in assessing a situation and what is at stake, to draw on experience, communicate with other participants and stakeholders and understand complexity.

Aligned with policies like the European Qualifications Framework, Creative Pragmatics offers a frame that supports learners in developing competences to navigate complexity and to deal with unpredictability. These competences are very important for addressing the multifaceted issues of our contemporary world. There is strong advocacy for STEM education that integrates multiple disciplines to prepare students for the complexities of modern challenges (Bybee, 2013, 2018). By emphasising active learning methods such as project-based learning (Zhou, 2016), problem-based learning (Tan, 2003), studio-based learning (Zairul, 2020), scholartistry (Shanks & Svabo, 2018), experiential learning (Coker et al., 2017) and participatory design (Bang & Vossoughi, 2016), Creative Pragmatics empowers students to go beyond the acquisition of bodies of knowledge, enabling them to develop twenty-first century skills such as critical thinking, creativity, collaboration, and communication, as well as transformative competencies (OECD, 2019), fostering adaptability and innovation. This prepares them to tackle real-world problems with innovative and strategic approaches, making a meaningful impact on society's most pressing issues (Davis et al., 2008).

From the inherent necessity of engaging with world complexities to the acknowledgment by policymakers, a need can be outlined to develop analytic and synthetic competencies, and to work on integrating theory and practice. This need is also emphasised by Friedman and Stolterman (2014) and Norman (2010).

1.5 Creative Pragmatics Introduced

There is a widespread concern to promote the learning of certain skills and competencies, bodies of knowledge and ways of knowing, deemed essential to navigating, and not getting lost and overwhelmed, in a world that is experienced to be growing in complexity.

This book proposes Creative Pragmatics as a synthetic concept that summarises a particular set of ways to navigate complexity. These performative strategies and tactics include skills and competencies (Grugulis & Stoyanova, 2011; Hoffmann, 1999), bodies of knowledge and ways of knowing (Svabo, 2021), as well as pragmatic means of managing institutions and projects, formulating and implementing strategy and policy in governmental and non-governmental agencies and in businesses, designing and delivering curricula and training programs.

For the purpose of this book, Creative Pragmatics is a dynamic framework for active learning in STEM education. It is not a fixed or static set of theories or methodologies. It is an approach, a stance, a mindset, a scaffold or framework which involves iterative learning through practice, by doing, by designing, by making, by making art, by engineering knowledge, by collaborating, by observing and reflecting, through dialogue, participation, and imagination.

Why do we propose this new synthetic concept? The components of Creative Pragmatics are time-served and well-founded, all around us. We propose the concept as a prompt, a nudge to (re)connect ways of knowing and acting that have tended to drift apart and even become siloed. We suggest the concept supplies a useful articulating focus in the contemporary debates around ways of engaging with complexity in policy and practice, particularly with reference to education, pedagogy, and professional development (Davis & Sumara, 2006; Davis et al., 2008).

The concept of Creative Pragmatics connects certain performative modes, strategies, tactics, to which we give priority, by grounding them in a transdisciplinary field summarised as a 'pragmatics'. By pragmatics we mean 'doings' and 'things done'. We associate pragmatics with 'things done', through the roots in the old Greek *pragma*, which is a deed, an act, something that has been done, while retaining the active verbal forms of *to do, to act and perform, doing*. In this, Creative Pragmatics is oriented on *praxis*—thoughtful practice that is situated (Lave & Wenger, 1991), and includes within its systems outlook materialities, material conditions (Hughes, 2000), artefacts (Svabo & Shanks, 2013; see Olsen, 2012 for a detailed unpacking of this materialism). The designation pragmatics also points to foundations in philosophical pragmatism, especially as manifested in educational philosophy and science and technology studies (Dewey, 1938; Putnam & Putnam, 2017; Rorty, 1982), and in linguistics, where pragmatics is the study of how language is best understood in social context.

Furthermore, the concept of Creative Pragmatics grounds and relates its pragmatic and performative strategies and tactics in terms of their creative capacities. Creativity is about coming up with new ideas, methods, and ways of thinking and doing things (Sternberg, 1998). We follow Bloom's revised taxonomy (Anderson & Krathwohl, 2001), where 'create' is the highest level of thinking and learning goals. This includes activities like designing, building, developing, and exploring.

We take creativity not to be a separate kind of activity or practice, but an aspect of pragmatics. This associates creativity with agency—capacities to act in the world, with efficacy—capacities to make a difference within worldbuilding and sense making (Putnam & Putnam, 2017). Creative agency influences all aspects of how we build our world. Agency refers to the ability of individuals or entities to shape the world around them. Society and culture are not merely backdrops in which people exist but emerge from our interactions (Latour, 1999, 2007). We do not simply belong to society; we actively create and transform it through our engagements with each other and our environment.

This transformative capacity is what we refer to as creativity—the ongoing reconstruction of our worlds through the agency of both humans and non-human participants (Sayes, 2013). Reality is a continuous process of formation and reformation (Pickering, 2010, referencing William James, 1975; Whitehead, 1978. For further exploration of these ideas, see Chap. 2 in this volume).

In summary, Creative Pragmatics is a synthetic concept addressing the pressing need to navigate the complexity of the world. It encompasses performative strategies and tactics, prioritising skills, competencies, knowledge, and pragmatic means across various domains, grounded in a transdisciplinary field referred to as 'pragmatics'. The concept emphasises thoughtful, situated practice (praxis) and integrates material conditions, artefacts, and a dynamic outlook on adaptive living systems. Rooted in philosophical pragmatism, science and technology studies, and art and design (Fig. 1.1), Creative Pragmatics associates creativity with pragmatics, aligning it with agency and efficacy in worldbuilding and sense-making.

We are very conscious that the deep roots of these three fields lie in long traditions, going back to antiquity. It is neither practical nor necessary to trace here the genealogy of Creative Pragmatics through Heidegger, Hegel, Vico, Spinosa and back to pre-Socratics, never mind eastern equivalents. Nevertheless it is useful to indicate that Creative Pragmatics builds on three overarching process-philosophical propositions that involve a constellation of six concepts in dynamic articulation.

- *Process and relations.* In knowing, understanding, acting-in-the-world, one does well to focus upon *processes and relationships*, the holistic dynamics of interconnected living systems — processes as well as products, verbs as well as nouns.

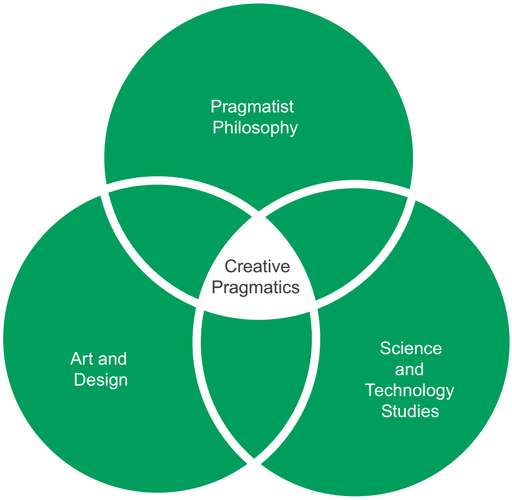

Fig. 1.1 Creative pragmatics: inspiration and sources of influence. Creative Pragmatics draws inspiration from pragmatist philosophy, science and technology studies, and art and design

- *Design and performance*. Design and performance are emergent, adaptive processes that evolve through ongoing interaction with the world. They are helpful models to think with in education where the emphasis is not on fixed outcomes but on the dynamic unfolding of action. Together, *design and performance* generate new possibilities for action and competence development, deeply entwined with the embodied, situated nature of knowing and doing.
- *Experience and agency.* Process-relations and design-performance are grounded in *experience*, another critical concept that connects the cognitive, sensory and affective in fields of embodied and creative *agency* — capacities to make a difference in the (re)productive dynamics of living adaptive systems.

We will outline this grounding for the concept Creative Pragmatics further in this chapter, especially in Sect. 1.8, and more in the next two chapters of this book, showing how these foundations offer critical insights into the ways that the skills and competencies, knowledges and ways of knowing of Creative Pragmatics may be learned and taught, in a recasting of pedagogy for the modi operandi of Creative Pragmatics.

1.6 Active Learning in STEM Education

How might we design learning to support the development of the knowledge, skills and competencies promoted by policy as essential for navigating a complex world? We need active learning approaches in STEM education, and these approaches cannot be developed through discipline-focused teaching of body of knowledge alone.

STEM is defined through the acronyms' constituent fields (science, technology, engineering, and mathematics). For many, STEM simply means science schooling.

However, in education research it is also an approach to education that focuses on the integration of these four areas, helping students learn by actively engaging with real-world problems and applying their knowledge. STEM education goes beyond content learning via memorisation and encourages practical problem-solving and critical thinking in science, technology, engineering, and mathematics. Stemming from a holistic and systemic approach to comprehend the world's complexity and interdisciplinary challenges, the goal is to prepare individuals with the literacy, skills and competences needed for professional practice in these fields (Sanders, 2009; Bybee, 2018; Larsen et al., 2022; Kristensen et al., 2024). STEM education, as an international educational phenomenon, is championed by entities like the Northamerican "National Science Teachers Association," advocating for educational responses to future workforce needs and the development of cross-disciplinary competencies (Bybee, 2013, 2018).

Despite STEM's role as a catalyst for societal investment in education, growth, and development, critics caution against potential pitfalls. They argue that an exclusive focus on STEM may narrow the educational purpose to problem-solving and technological development, relegating mathematics and natural sciences to auxiliary disciplines that need to be redesigned and technologised for relevance (Schmidt, 2019).

Active learning methods are essential in addressing these concerns, as they provide students with the opportunity to engage directly with subject themes through interdisciplinary approaches. Design principles for STEM education stress its interdisciplinary nature, support for individual STEM domains, and meaningful integration based on engagement with complexity, and attention to specific context (Bybee, 2018; Svabo et al., 2024). Whether seen through the lens of real-world connections, problem-solving, or an instructional approach, STEM education underscores the importance of authentic, problem-based learning rooted in science, mathematics, technology, and engineering (Kelley & Knowles, 2016; Shaughnessy, 2013; Johnson, 2013).

The importance of active learning methods has been highlighted in the pursuit of STEM education innovation (Felder & Brent, 2016; Penprase, 2020). These methods call for a broad range of pedagogical strategies that encourage and engage students as active participants in their learning experience (Cattaneo, 2017).

As Lee et al. (2018) have described, student active learning refers to instructional approaches that actively engage students in their learning process through collaboration and discussions rather than having them passively receive information from their instructors.

The basic meaning of the term active learning is that teachers should use teaching practices that actively engage students. An important part of active learning is that students explore and develop their own thoughts, feelings, and standpoints (Silva et al., 2022), as well as communicate and collaborate with others (McGill & Beaty, 2013).

According to Bonwell and Eison (1991), active learning is "anything that involves students in doing things and thinking about the things they are doing" (p. 2). By this, active learning highlights that students engage in reading, discussing, and writing, exploring their own attitudes and values. Emphasis is placed on developing students' skills and competencies instead of transmitting, as well as assimilating, data and information. A key point in active learning is that students engage in higher-order thinking such as analysis, synthesis, and evaluation (Børte et al., 2023).

Active learning gives students more opportunities to learn subject matter and work with creativity, critical thinking, hands-on skills, collaboration, and communication (Silberman & Biech, 2015; Revans, 2017). This helps students develop deeper understanding and it helps them apply theoretical concepts in practice.

Pedagogical methods such as design thinking (Wrigley & Straker, 2017; Goldman & Zielezinski, 2022), learning through making (Halverson & Sheridan, 2014), aesthetic learning (Uhrmacher, 2009; Shanks & Svabo, 2018) and playful learning (Honey, 2013) have been applied with similar purposes of active student participation.

Through such methods, students' engagement, critical thinking, problem-solving, and collaboration skills are enhanced (Tytler, 2020). These methods complement knowledge acquisition through rote learning with active, authentic learning experiences that better prepare students for the complexities of the modern world (Davis & Sumara, 2006; Zhou, 2016).

Integrated STEM approaches (Kelley & Knowles, 2016), SSI-approaches (Socio-Scientific Issues) (Zeidler, 2016), Inquiry-Based Learning (Sutaphan & Yuenyong, 2019), Design-Based Learning (Basham & Marino, 2013), Project and Problem-Based Learning (PBL) (Zhou, 2016), Place-Based Education (Gruenewald & Smith, 2014) and STEAM—incorporating the arts with STEM subjects (Bertrand & Namukasa, 2020) are all pedagogies that promote interdisciplinary collaboration and problem-solving.

These pedagogies typically seek to bridge the traditional boundaries between the science, technology, engineering, and mathematics disciplines through interdisciplinarity (Davis et al., 2019). They emphasise real-world orientation and promote holistic understanding (Tytler, 2020), underscoring the importance of skills development in critical thinking, decision-making and participation in discussions about issues such as climate change, ethics in the use of artificial intelligence or genetic engineering (Zeidler, 2016; Sutaphan & Yuenyong, 2019).

Furthermore, these approaches often integrate hands-on or practical aspects in educational situations (Kennedy & Odell, 2014; Kelley & Knowles, 2016), illustrating the overlap between active learning and integrated STEM education.

The next section on Creative Pragmatics will expand on these ideas, demonstrating how this concept can enhance both active learning and integrated STEM education. Creative Pragmatics offers a framework that incorporates creativity and agency into the learning process. This equips students with the competence to navigate complexity.

1.7 Challenges for Active Learning in STEM Education

STEM education often highlights the need to move beyond the boundaries of individual disciplines and embrace a more holistic approach in inquiry and problem-solving. However, traditional educational models frequently limit students to low-level cognitive tasks such as recalling facts in isolation, which can hinder their development of higher-order thinking skills necessary for tackling complex and ambiguous problems (Kennedy & Odell, 2014). Without having developed higher-order thinking skills and metacognitive capability, students may struggle to apply their learning in competent action (Thibaut et al., 2018).

A significant challenge in STEM education is the integration of interdisciplinary learning, which is essential for holistic understanding, but also often underdeveloped in current practices. This calls for more attention to interdisciplinarity in STEM and STEM integration (Nadelson & Seifert, 2017). As Anderson and Li (2020) have suggested, combining inquiry-based learning with an integrated STEM approach can provide opportunities for students to develop a range of general capabilities, such as critical thinking, self-direction, creativity and communication. However, without a strong interdisciplinary framework, students may struggle to connect ideas across disciplines and gain meaningful insights when working on real-world problems (Zhou, 2012, 2016; Holmes et al., 2018). This resonates with ongoing scholarly discussions about discipline-based science education and STEM integration (Larsen et al., 2024; Svabo et al., 2024), and indicates the need for change towards a paradigm of co-creation, with ideas including collective forms of practice and knowledge (Dollinger et al., 2018).

STEM education takes us beyond traditional disciplinary boundaries, requiring both teachers and students to develop theoretical, epistemological, methodological, and practical skills (Block et al., 2022). However, current educational models and systems often lack the flexibility needed to adapt to rapidly changing technologies and societal needs (Jantsch, 1972).

Active learning advocates a shift toward student-centred learning models and experiential and participatory pedagogies (Bonwell & Eison, 1991; Honey, 2013). Despite the benefits of these pedagogical methods, existing educational systems and teaching practices often resist change due to entrenched traditions and beliefs that 'real science teaching' should be content-focused and lecture-based. Both teachers and students may be accustomed to traditional methods and sceptical about deviating from established practices, believing that maintaining traditional forms of teaching and disciplinary boundaries is necessary (Kossybayeva et al., 2022).

In active learning practices, teachers become education designers, and there is a demand for them to teach in ways that are dialogical, open-ended, and exploratory. The teacher's role shifts from being an expert who imparts knowledge to students to one who facilitates learning and provides opportunities for students to talk, experiment, and actively engage. This requires teachers to develop creative, reflective, and research-based methods to improve their teaching (Li et al., 2019) and necessitates ongoing support and training.

Moreover, existing assessment and evaluation systems can hinder active learning approaches. Innovative STEM methods often focus on process-oriented learning, critical thinking, and collaborative skills, which may not align with traditional assessment methods (Sinatra et al., 2015). Designing assessments that foster skills like critical thinking, creativity, communication, and collaboration while meeting educational standards can be challenging (Margot & Kettler, 2019).

To support changes in educational systems, it is essential to connect students and educators with STEM fields and professionals (Dollinger et al., 2018), provide global and multi-perspective viewpoints (Kelley & Knowles, 2016), encourage outreach activities in both formal and informal learning settings (Bell et al., 2016), and select appropriate technologies to enhance teaching and learning (Kossybayeva et al., 2022). Exploring transdisciplinary settings and interactions between academic and non-academic actors is also necessary, which involves efforts in coordination, communication, and logistics (Balsiger, 2015).

These challenges indicate the need for Creative Pragmatics, which can enhance active learning in STEM by promoting innovative problem-solving, interdisciplinary integration, and adaptable learning models. The chapters of the book explore how Creative Pragmatics can be integrated into STEM education, showing examples of educators and students developing competencies to navigate a complex and dynamic world.

1.8 Creative Pragmatics and Tackling the Challenges of STEM Learning

How can we overcome these challenges in STEM education? We bring together various proven educational philosophies and sources of inspiration to urge a shift towards active learning. In this we propose Creative Pragmatics as a synthetic concept that will contribute to a transformation of how STEM disciplines are taught.

As mentioned, it is widely acknowledged that problem-solving, critical thinking, creativity, communication skills, emotional intelligence and transformative competencies are essential in addressing contemporary challenges. This book argues that such skills and competencies can be unified under the umbrella concept of 'Creative Pragmatics'. An underpinning rationale is that our present day problems can not be handled by doing more of the same. We need new, or rather refreshed approaches to how to live in, perceive and come to know the world, and these approaches have to foster skills and sensibilities which make it possible to address human and environmental needs in production, consumption and all aspects of a circular economy.

Science and technology studies (STS) provides a strong inspiration for Creative Pragmatics. STS provides nuanced understanding of scientific and technological developments, highlighting the role of instrumentality in science, the agency of materiality and the enrolment of heterogeneous forces in the making of facts. We follow those trajectories in science and technology studies which suggest that knowledge is something that we perform and achieve, and we consider such productive work to be creative. By calling knowledge creative, we don't mean it invents the world like a fictional story. Instead, we mean that knowledge and skills are accomplishments—creative accomplishments. Knowledge and skills are crafted and developed by people through their interactions and activities in the world. This process involves not only humans but also non-human elements and agents (Latour, 1999, 2007; Rathje et al., 2012 for a particular interdisciplinary science; for more on this, see Chap. 2 of this volume).

Creative Pragmatics is a dynamic framework for active learning in STEM education. It is not a fixed or static set of theories or methodologies. It is an approach, a stance, a mindset, a scaffold that involves iterative learning through practice, by doing, by designing, by making, by making art, by engineering knowledge, by collaborating, by observing and reflecting, through dialogue, participation, and imagination.

Inspired by pragmatism and pragmatist educational philosophy (Dewey, 1938; Putnam & Putnam, 2017; Rorty, 1982), Creative Pragmatics emphasises the active aspects of learning and the potential of education for societal change. This perspective underscores the importance of experiential education and the integration of theory and practice, as learners engage with the world through concrete experience, reflective observation, abstract conceptualisation, and active experimentation (Kolb, 1984).

In resonance with Pickering's (2010) prompt to sketch another future for education, Creative Pragmatics seeks to intervene in our very approach to modelling knowledge. Following Pickering's call for performative, open-ended models that go beyond mere representation, Creative Pragmatics echoes a 'more-than-representational' ethos. The concept embraces the notion of active, creative engagements with the world, epitomised by the act of making (Honey, 2013; Kennedy & Odell, 2014; McGill & Beaty, 2013).

That active agency is inherent in learning and understanding, reinforces the tenet that learners are not passive recipients but active creators of knowledge (McGill & Beaty, 2013; Vaughn, 2021). This approach to modelling knowledge places active engagements with the world as pivotal in knowledge making, learning and understanding (Svabo, 2021). Creative processes of making, designing, producing are key in developing knowledge, skills and competencies (Risopoulos-Pichler et al., 2020; Zhou, 2016).

Working creatively and with design and aesthetics, the latter broadly defined as perceptual and evaluative aspects of making, is a way of engaging in world-making, be it in the form of production of knowledge artefacts, systems or process design (Eisner, 2002). Design is purposeful practice, well conceived as the planning and management of making, of production and indeed distribution and consumption, all as creative engagements with world and environment (Honey, 2013; Wrigley & Straker, 2017). The field of design thus injects a critical dimension into Creative Pragmatics, spotlighting the interconnections between meaning and materiality (Hughes, 2000), and the aesthetic, processual and material mediation of innovation, problem-solving, ideation, and the iterative character of creative processes.

Creative Pragmatics is associated with concepts of creativity and agency, draws inspiration from studies on aesthetics, art and design, and highlights the situated performance of knowing. This relates to notions of situated learning (Engeström & Cole, 2021; Miner & Nicodemus, 2021). As Lave and Wenger (1991) described, learning, thinking, and knowing are relations among people in activity, within, and arising from the socially and culturally structured world. Creative Pragmatic approaches encourage learners to actively engage in inquiry, experimentation, making, and collaboration, inviting them to become active participants in their own learning journey.

The concept of Creative Pragmatics is rooted in the pragmatic theory of education (Dewey, 1938; Rorty, 1982), which believes that learning is active and that education is an instrument of change. Education should pay attention to learners' experiences with a process that can help integrate theory and practice. This emphasises the values of experiential education and pedagogical ways of learning by doing (Dewey, 1938). As Kolb (1984) suggested, learning occurs in a cycle through concrete experience, reflective observation, abstract conceptualisation, and active experimentation.

The convergence of these diverse fields involves their shared emphasis on active engagement (Kennedy & Odell, 2014), adaptability (Pickering, 2010), contextuality (Engeström & Cole, 2021), material mediation and the intricate interconnectedness of human experience. Together they are important threads in Creative Pragmatics as a multidimensional and dynamic concept that honours the performative, experiential, mediated, situated and transformative nature of human interaction with knowledge and the world (Svabo, 2021).

In summary, Creative Pragmatics emerges as a concept that synthesises insights from science and technology studies, pragmatist educational philosophy, art and design studies. This transdisciplinary foundation highlights the interactive, adaptive, aesthetic and contextually grounded nature of human endeavours that underscores the continuous and reciprocal relationship between individuals and their environment in the process of learning and meaning-making. By both shaping the world and constructing meaning within it, Creative Pragmatics embodies Vico's profound adage "verum ipsum factum" (Morrison, 1978), emphasising that truth is in what is made, that truth itself is not merely discovered but actively forged through acts of making and engagement.

By embracing Creative Pragmatics, STEM education can transcend traditional teaching methods and foster a holistic learning environment that empowers learners. We highlight Creative Pragmatics as a practical and philosophically grounded approach to how educators can design learning. Design informed by Creative Pragmatics inspires teachers to create learning situations where students actively build skills and competencies in knowledge work, including synthesis and integration between disciplines, the capacity to carry out self-leadership, critical analysis, creative problem-solving and communication with experts and non-experts.

Creative Pragmatics is a dynamic and adaptive approach to knowledge-building, sense-making, and problem-solving. This encompassing philosophy—or even paradigm—is characterised by an array of dimensions or vectors, with Creative

Pragmatics serving as an embodiment of infrastructuring premises or starting points, frames or mindsets within which one works, and modi operandi or orientations guiding creative practice (praxis). To use a metaphor of making or building: one establishes infrastructures and starting conditions, erects a scaffold or frame, a mindset or design philosophy, and then gets on with the making (see Table. 1.1).

Our summary overview is not prescriptive but suggestive. With knowledge intricately intertwined with perception, purpose, and imagination, a core tenet of Creative Pragmatics is its performative understanding of knowledge generation, bolstered by a pragmatic outlook (Bell, 2006). This underscores that knowledge extends beyond mere representation of a world-out-there separate from the knower and their discourses. Hands-on making, tinkering, and bricolage find home within Creative Pragmatics, synergising with an embedded, contextual, and relational disposition and orientation on practice as engagement and intervention. Creative Pragmatics prompts iterative and probing engagements and interventions, akin to riding wind and waves, sailing and surfing in a dynamically changing ocean, fostering adaptability and open-ended exploration (Svabo, 2021; Shanks & Svabo, 2018). As with engineering and design, Creative Pragmatics is not a methodology per se, though it might employ specific methodologies to serve its adaptive, located, opportunistic disposition and orientation. It is well conceived as finding way or ways (the old Greek root of *meta-hodos* is road or pathway). Consider how a design team may use quantitative and qualitative methodologies to come to know and gain empathy with a user community, use various techniques of creative ideation in exploring possible interventions, employ materials science and electrical engineering in realising a product or service, delivered through appropriate processes of manufacturing and distribution, to be assessed for use and worth to a user community. In such ways

Table 1.1 Understanding Creative Pragmatics. This table provides an overview of Creative Pragmatics, deriving the concept from deep roots in philosophical principles, influenced by science and technology studies and pragmatism, as well as by art and design. Overall, this table highlights how Creative Pragmatics integrates various dimensions to provide a holistic and transformative educational framework and practical orientations for pedagogy and policy

Infrastructures/premises	Frames within which one works/mindsets	Modi operandi/orientations on practice
Focus on process and dynamics in embracing openness and contingency	Holistic systems thinking	Iterative making as specific and located temporary interventions/solutions
Transactional relationships and contextual sensitivity	Cybernetic and adaptive sensory engagement	Participation, in distributed responsibility and autonomy
Performative understanding of knowledge	Accounting for participant context through ethnographic sensitivity in cultural diversity	Collaboration and co-creativity in teamwork and shared agency
Transdisciplinary engagement through (learner) experience	Design thinking and learning-by-doing, active experiential learning	Foresight, imagination and future worldbuilding
	Sources of influence	
Pragmatist philosophy	Science and technology studies	Art and design practice

Creative Pragmatics integrates problem-solving and decision-making processes through flexible, adaptive, experimental, and open-ended problem engagement.

So one can mix and match the components of Creative Pragmatics outlined in Table 1.1 according to need and experience, opportunity and potential. If we shift attention to pedagogy and STEM learning, Creative Pragmatics might prompt teaching strategies such as active learning, problem-based learning (PBL), and inquiry-based learning, by underscoring their practical orientations: iterative making as specific and located temporary interventions/solutions; participation, in distributed responsibility and autonomy; collaboration and co-creativity in teamwork and shared agency; foresight, imagination and future worldbuilding. These practical orientations can guide on many levels: as a teaching strategy and also on systemic, educational policy level.

Creative Pragmatics emphasises a learner-centred focus, underlying the importance of agency. Thus one of the key components is the focus on participant learning experience. Through teaching strategies embedded in Creative Pragmatics, participants (learners, as well as teachers) pursue hands-on experience: materially, physically embedded, tangible learning; adaptive variation of methods, spaces, and interactions; autotelic and playful learning; all related to specific educational content. There is a balance between cognitive and affective learning; the process is no less important than the result, where experiences of learning complement bodies of knowledge in the iterative processes that are Creative Pragmatics. Creative Pragmatics in active STEM learning thus equips learners with the capacity to engage with complexity, embrace uncertainty, and employ innovative strategies to address multifaceted challenges in STEM fields and beyond.

We seem to be the first to introduce in a scholarly milieu the concept 'Creative Pragmatics'. But neither the concept nor its dimensions and dynamic components stand isolated. It is quite appropriate to assert that Creative Pragmatics is nothing new. We have indicated in Sect. 1.5 of this chapter the diverse and deep roots of the concept. For this book particularly we draw on earlier work in pragmatist educational philosophy as well as learner-centred, production-oriented and constructivist pedagogies and teaching approaches. Creative Pragmatics adds a fresh action-oriented outlook by *integrating* various educational philosophies and pedagogies. It contributes to discussions in science education research by aiming to make it tangible for science educators in achieving learning goals for skills and competencies outlined in frameworks like the European Qualifications Framework or relevant national versions. By embracing Creative Pragmatics, STEM education is positioned to move beyond traditional teaching methods, cultivating a holistic learning environment that empowers learners to navigate a complex and uncertain world.

1.9 The Contents of This Book

This book provides research-based foundations for Creative Pragmatics in active learning and illustrates meaningful studies through various theoretical perspectives, research methods, and pedagogical models across different contexts and cultures. It also incorporates lessons learned and proven practices focused on the interaction between active learning, educational design, and participatory pedagogy in STEM education.

The collection of 13 chapters explores discussions on creative learning, teacher-student interactions, professional learning, support for instructors, assessment, science literacy, hands-on skills, problem-based learning, project-based learning, student agency, twenty-first-century skills, and national science education innovation. The collection of chapters includes voices from various educational levels and disciplines, a polyphonic format that suits the Creative Pragmatics approach.

This chapter, the book's Chap. 1, "Creative Pragmatics for Active Learning in STEM Education" launches the book by discussing the need for new knowledge models and the importance of learning to navigate in complexity. The chapter defines Creative Pragmatics as a synthetic and integrative concept for active learning in STEM education. Creative Pragmatics integrates performative models of knowledge with pragmatic educational philosophy, emphasising creative agency and active engagement.

Chapter 2, "Creative Pragmatics—Situated Performances of Knowing" provides theoretical and philosophical points of orientation, drawing inspiration from pragmatism and science and technology studies and connecting with art and design practice. Creative Pragmatics emphasises situated performances of knowing, agency and creativity—essentially as iterative processes of learning through doing and dynamic sensemaking. Art and design contribute to the principles and concepts underpinning Creative Pragmatics.

Chapter 3, "Creative Pragmatics—Knowing and Competence in a Complex World" lays the groundwork for Creative Pragmatics by exploring the idea of complexity. Complexity makes it challenging to use traditional ways of predicting and simplifying things, since it cannot be fully understood or predicted. The chapter compares how we usually think about the relationship between science and the world with a performative understanding. This new perspective requires us to rethink what we know, the skills we have, and the competencies we develop. While endorsing a competence-based approach, Creative Pragmatics aims to overcome its limitations. It emphasises that competence-based learning, although valuable for practical skills, should not succumb to reductionism but instead uphold a holistic view that acknowledges the situated and dynamic nature of competencies. This chapter concludes the three introductory chapters and sets the stage for the following case chapters, demonstrating fresh approaches to competently dealing with the complexities of our world.

Chapter 4, "Active and Agentic: Participant-Directed Inquiry in an Introductory Science Programme," demonstrates the critical importance of creative agency within the framework of Creative Pragmatics, where learning is co-designed, and agency is integral to participatory learning in the design process. Through a qualitative case study of two student projects at Roskilde University, it highlights how an open inquiry approach enables students to navigate and simplify complex situations, fostering agency within project groups. The research illustrates how students leverage natural science to address real-world challenges, such as those found in the shipping industry. The chapter underscores the transdisciplinary nature of the program, as self-directed inquiry extends beyond traditional disciplinary boundaries to engage with complex societal issues.

Chapter 5, "Artefacts and Creative Learning in Mathematics Education", examines the artefact and material components of creative and playful learning environments, highlighting the importance of user-centred design through situated experiences and a connection with arts practice—key elements of Creative Pragmatics. The chapter challenges the isolation of learners by activating agency not only in the learners but also in the artefacts within the learning environment. It bridges the fields of artefact design, creative learning, and mathematics education, focusing on a concrete case of a booklet design process guided by Creative Pragmatics principles. Through the first author's reflective autoethnography, the chapter demonstrates the pragmatist idea that we are part of what we seek to understand. Insights from three rounds of user testing inform both the booklet's further development and broader considerations of artefact-mediated creative learning environments in mathematics and STEM education. By discussing the values of art, the chapter also offers inspiration for the future of mathematics and STEM education, emphasising the role of artefacts in fostering creative, playful learning environments.

Chapter 6, "Summative STEM Competence Assessment: Affect-Sensitive Learning," explores the integration of competencies and affect in designing holistic summative assessments for integrated STEM education. By leveraging a theoretical framework that combines cognitive learning aspects with affect theory, the chapter introduces the concept of affect-sensitive learning to offer a comprehensive perspective on assessing STEM competencies. A case from the LabSTEM+ project highlights the significance of considering affect in both STEM teaching and assessment. The study examines how affect influences the analysis of summative assessments, focusing on students' STEM competencies and their affective experiences. The case study reveals a dynamic interplay between STEM competencies and the affective domain, showing how materials like pipes and water enhance students' engagement, motivation, and autonomy. This research contributes to a deeper understanding of the role of affect in STEM education assessment and highlights the importance of integrating affective aspects to promote a more holistic approach to learning and assessing STEM competencies, which is essential for making Creative Pragmatics work in practice.

Chapter 7, "How to Start Strong: Different Approaches for Crafting Project Briefs with Corporate Sponsors for Global Innovation and STEM-Based Team Projects," highlights the importance of teaching tools like project briefs in putting Creative Pragmatics into action. The study marks the significance of the starting point in project-based active learning, emphasising its crucial role in the iterative, never-ending learning process that defines Creative Pragmatics. By analysing a rich data set of 68 project briefs from 19 partner universities over a decade, drawn from a long-running project course taught at Stanford University and the SUGAR Network, the chapter explores different approaches to framing these briefs, which are key to facilitating creative interventions in complex scenarios. The research found that corporate sponsors sought seven different types of project outcomes, with varied phrasing strategies such as "how might we" and "we dream..." to spark imaginative thinking. Additionally, over a third of the briefs focused on mid-term innovation horizons. The chapter concludes with a two-question guide for crafting project briefs with corporate sponsors, helping to ensure that student projects start from a stronger position.

Chapter 8, "FabLabs and the Maker Movement: Learning through Making," establishes the programmatic coherence of the maker movement as expressed through Creative Pragmatics. The chapter explores deeper associations of design processes within "epistemologies of the hand," highlighting the transdisciplinary reach of design-based methodologies. It gives shape and substance to the principle of embodiment, emphasising that active learning is not just cognitive but also affective and located in corporeality. Starting with the question, "Is 'Making' hype?", the chapter examines the ethos of the Maker movement as a new way of empowering innovation, learning, and communities. Drawing on seven years of experience from running the FabLab RUC at Roskilde University, the chapter proposes a maker mindset through six propositions, positioning "making" as a complementary methodology to design thinking.

Chapter 9, "Use of Spaces for Active Learning in University STEM Education", emphasises that space shapes the people who inhabit it, highlighting the importance of how individuals interact with their learning environment. This chapter argues that teachers' use of physical learning spaces in higher education can support active learning if they engage in a Creative Pragmatic process of reflecting and experimenting. The chapter highlights that spatial competence—understanding how to effectively use and adapt learning environments—plays a crucial role in facilitating active learning. By presenting cases where spatial competence is demonstrated, the chapter provides examples of how spaces can be manipulated to enhance learning experiences. It also offers strategies for helping teachers develop this competence by creating opportunities for dialogue about space in learning. The chapter ultimately seeks to inspire educators to engage in Creative Pragmatics by planning, conducting, and reflecting on the use of classroom spaces to promote relational and situated learning in STEM.

Chapter 10, "Design Studio for Active Learning", explores how design studios serve as dynamic learning environments that facilitate the development of competence by engaging students in active, situated learning processes. Through case studies from programs at Columbia, Stanford, and Nebraska, the chapter outlines key principles of pedagogical scaffolding that guide students through a design process. This process includes defining and briefing a problem, researching and assessing contextual issues, ideating, prototyping, and participating in studio-based critique, all while anticipating the real-world application of solutions. By focusing on how students interact with and adapt to their learning environments, the chapter demonstrates how competence extends beyond knowledge and skills to include the ability to use them in context-sensitive and collaborative ways. The concept of Creative Pragmatics offers a perspective on architecture, with further expansion of STEM through the experiential lifeworlds of physical structures, engineering, building, design. In this chapter, this wide scope is grounded in a case-study in studio-based learning focused on the design of future urban infrastructures, an epitome of complexity.

Chapter 11, "A Pedagogy of Enactment: Creative Rehearsals and Feedback Literacy in Science Teacher Education", explores the critical role of 'learning about learning' within the framework of Creative Pragmatics, emphasising the importance of practice and experimentation for those who shape classroom experiences. This chapter investigates how science teachers benefit from ongoing processes of rehearsal and reflection, highlighting the concept of performance as a fertile ground for bridging theory and practice. It demonstrates how rehearsal, enactment, scenario-building, and improvisation can be powerful tools for practice-based learning. The concept of 'creative rehearsal' illustrates the role of imagination in reconciling the tensions between theory and practice, while 'feedback literacy' is presented as a key pragmatic competency in the dynamic, iterative process of learning by rehearsing. Through this exploration, the chapter offers valuable insights into how pre-service science teachers can develop their teaching practices through active engagement and reflective practice.

Chapter 12, "Innovating Science Education at a National Level", presents a case study in navigating complex adaptive systems through the lens of Creative Pragmatics. The chapter examines the challenges of innovating science education in Denmark, focusing on policy, leadership, team dynamics, and large-scale interventions. It advocates for a holistic, ecosystemic perspective that works across administrative silos, applying abductive sensemaking iteratively, adaptively, and collaboratively. This approach is particularly emphasised in bridging large-scale initiatives with local efforts to better connect science and society. Through an auto-ethnographic assessment of the Danish Science Academy's efforts, the chapter explores how collective leadership, boundary-spanning, and building informal learning communities can drive long-term, sustainable change in science education. This analysis contributes to the broader Scandinavian discourse on large-scale educational innovation, highlighting the interconnectedness of systems in the process of educational reform. This shows how a Creative Pragmatics approach is not restricted to the classroom but can be applied broadly at all levels of learning.

Chapter 13, "A Call to Action for Embedding Creative Pragmatics in STEM Education", serves as a call to action for STEM educators, policymakers, and educational institutions to adopt Creative Pragmatics as a means to enrich current learning models with more participatory, hands-on, and student-directed approaches. This final chapter synthesises the wide range of case studies and methodologies presented throughout the book, drawing out implications for educational policy, funding models, and pedagogical practice. It argues that by integrating Creative

Pragmatics into STEM education, all stakeholders can help cultivate a pipeline of scientific and technical talent equipped to navigate the complexities of the real world. By bridging thinking and doing, this chapter explores where the dialogue on Creative Pragmatics can go next and how different stakeholders can more actively embrace and implement active learning in STEM education.

This book is about Creative Pragmatics and itself is a creative collaboration work. It indicates efforts of a group of experts from the US and Europe, including Stanford University and Columbia University in the US, University of Southern Denmark, Technical University of Denmark, Roskilde University, University College of Southern Denmark, and Blekinge Institute of Technology in Sweden.

Researchers, academics, STEM educators, advanced-level students, practitioners, policy makers, and government officials will find this book useful in furthering their research and rethinking how to develop the practice of STEM education in the future.

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