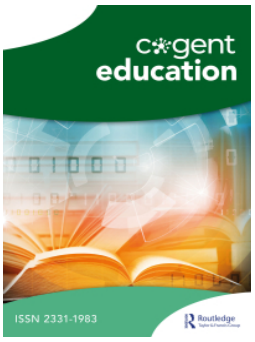


Cogent Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaed20

Towards transdisciplinarity in global integrated science-arts practices in education? A Janus approach

Oded Ben-Horin, Menelaos Sotiriou, Magne Espeland & Giedrė Strakšienė

To cite this article: Oded Ben-Horin, Menelaos Sotiriou, Magne Espeland & Giedrė Strakšienė (2023) Towards transdisciplinarity in global integrated science-arts practices in education? A Janus approach, Cogent Education, 10:2, 2287895, DOI: 10.1080/2331186X.2023.2287895

To link to this article: https://doi.org/10.1080/2331186X.2023.2287895

Ben-Horin et al., *Cogent Education* (2023), 10: 2287895
https://doi.org/10.1080/2331186X.2023.2287895

cogent education

CURRICULUM & TEACHING STUDIES | RESEARCH ARTICLE

Towards transdisciplinarity in global integrated science-arts practices in education? A Janus approach

Oded Ben-Horin[1]*, Menelaos Sotiriou[2], Magne Espeland[1] and Giedrė Strakšienė[3]

Received: 09 June 2023
Accepted: 21 November 2023

*Corresponding author: Oded Ben-Horin, Department of Arts Education, Western Norway University of Applied Sciences, Stord, Norway E-mail: oded.ben@hvl.no

Reviewing editor:
John Chiang, Communication and Media, State University of New York, United States

Additional information is available at the end of the article

Abstract: Recent years have witnessed significant growth of interest in science-art integration in schools as an approach to creative teaching and learning. This conceptual turn in education implies profound institutional and philosophical changes. Central to this turn has been the development of Science, Technology, Engineering, Arts, Math (STEAM) education. In this article, we detail a progression from an existing model of pedagogical principles and educational objectives in science education within a global STEAM education environment, Global Science Opera, towards shared pedagogical principles and educational objectives in both science

ABOUT THE AUTHORS

Oded Ben-Horin is Head of Department of Arts Education at Western Norway University of Applied Sciences. He is the coordinator of the "Global Science Opera" initiative. He has led several European Commission projects in the field of creative, inter-disciplinary education, and has held numerous lectures within that field. Oded is a music educator, and a jazz vocalist, composer and lyricist. He has a PhD in Arts Education, a masters degree in music performance and Bachelor Degrees in Business Administration and Musicology. Orcid Id: 0000-0002-8658-0768.

Menelaos Sotiriou is a science educator and communicator with a background in Applied Mathematics. He has 24 years of international work experience. He is the President and Founder of Science View. He holds a master's degree in Total Quality Management. He currently works in the field of science education and communication. His main research focus is the introduction of creative and innovative methodologies in STEAM education. His special interest in the field of Education is the development of self-reflection tools to measure the innovation and e-maturity of school units. Orcid Id: 0000-0001-6252-297X.

Magne Espeland is professor emeritus of Music and Education at West Norway University of Applied Sciences (HVL). His specialities are curriculum and resource books development and innovation in music education, educational design studies, research methodologies for education, master and Ph.D – supervision, research and project leadership, consultancy services and program evaluation. He was Principal Investigator in three research projects funded by the National Research Council of Norway. Professor Espeland has also recently worked as an advisor and evaluator for the Swedish and Portuguese Research Councils. He was member of the International Society for Music Education Board, and chaired its World Conference in Bergen (2002). He appears regularly in PhD candidate viva assessment and as keynote speaker in many countries, including Norway, Sweden, Denmark, Great Britain, China, Estonia, Ireland and the US. Orcid Id: 0000-0002-3706-4281.

Giedrė Strakšienė, PhD in Social Sciences, Educology, is Associate Professor at Klaipeda University. She was a postdoctoral researcher at the Department of Arts Education at Western Norway University of Applied Sciences during the years 2021–2022. Her main research area focuses on development of communicative competence; various teaching and learning drama methods which are applicable in development of communicative competence; interaction between information visualization and communication, and implications of these phenomena for contemporary art-science contexts in education. Orcid Id: 0000-0001-8533-0276.

cogent • oa

and arts education within that same environment. In this work, we rely on a transdisciplinary approach towards the integrated disciplines and the educators who teach them. We outline the need for the new, integrated approach to be validated in other, empirical, contexts in order to establish its capacity in the field of creativity in education, and specifically in global STEAM environments in order to ensure its relevance to teaching and learning of a kind which strengthen students` knowledge, abilities and democratic and inclusive values. We propose the Janus metaphor for the new approach as it represents the possibility of having a double perspective of a single focus of attention. We conclude by pointing at limitations of discipline integration in which pedagogical principles in science education are not in harmony with the pedagogical principles in arts education.

Subjects: Theory of Education; Classroom Practice; Curriculum Studies

Keywords: transdisciplinarity; science-art; integration; global science opera; Janus; students

1. Introduction

Recent years have witnessed significant growth of interest in science-art integration in schools as an approach to creative and engaging teaching and learning. This conceptual turn in education implies profound institutional and philosophical changes for schools which choose to embrace the integration of disciplines (Colucci-Gray et al., 2017; Marshall, 2014). Central to this turn has been the development of Science, Technology, Engineering, Arts, Math (STEAM) education (Yakman, 2008). Based on, and building further upon, Science, Technology, Engineering and Math (STEM) education, STEAM is a framework for integration of the Arts with the STEM disciplines in educational settings (ibid). Though STEAM education has achieved popularity in recent decades, it is still a hybrid concept, and its underpinning ideas and pedagogies need to be more clearly stated (Colucci-Gray et al., 2017). Therefore, while aiming to cover various educational practices, STEAM education as a concept still lacks clarity (ibid). A main issue which requires clarification is what the "STEM to STEAM agenda" (ibid, pg. 7) implies with regard to inter-relations between the integrated disciplines. Specifically, it is important to address the question of whether STEAM educational contexts imply interdisciplinary or transdisciplinary relations[1] between disciplines (Klein, 2006). In interdisciplinarity, discipline integration typically serves the study of an overarching theme, problem or idea, yet that integration is not the main goal of the educational process (ibid). Transdisciplinarity represents the greatest degree of integration, in which divisions and differences between disciplines become unclear, and in which discipline integration constitutes a goal in itself (Klein, 2006). In transdisciplinarity, connections between disciplines are magnified, leading to new educational designs in which learners themselves initiate learning collaboratively. Transdisciplinarity is understood as having potential to solve problems for which creative working methods, stakeholder involvement, and socially responsible science are required.[2]

In this article, we aim to provide a renewed rationale for STEAM education by taking a step beyond what we understand as the current state of the art in science-art integration, in the form of a conceptual model of transdisciplinarity in STEAM education. We approach this by simultaneously detailing pedagogic principles and educational objectives in both science and[3] the arts, within a single STEAM education environment, Global Science Opera (GSO) (Global Science Opera, 2016). This effort is based on our own experiences and participation in several science-art integration initiatives,[4] some of which had science education goals as their main focus, while others turned to science as inspiration for arts education activities.

Global Science Opera (GSO) is the first opera initiative in history to produce and perform educational operas as a global community. It is a network of scientists, art institutions, schools, universities, and projects, in all of the inhabited continents. GSO exists at the meeting point of science and art, of students and scientists, of all human cultures, of research and practice. The GSO produces annual Global Science Opera productions during which a global community explores interwoven science, art and technology within a creative and democratic inquiry process (Ben-Horin, 2014a; Global Science Opera, 2016; Sotiriou et al., 2021; Straksiene et al., 2022; Urbaniak et al., 2021). GSO is situated and implemented in the context of global STEAM education, as one of several international STEAM initiatives (Chappell et al., 2019). It has roots in creative education research and development initiatives of the European Commission (Ben-Horin, 2014a; Sotiriou et al., 2021) and the European Economic Area (Sousa et al., 2016). Examples of scientific themes which have provided inspiration for GSO productions are gravity, the creative human mind, energy, marine life and sustainability, eco-system restoration, and the exploration of space made possible by the James Webb Space Telescope. While always directly relating to the opera's scientific theme and main story-line, teachers and students at each GSO location exercise freedom with regard to how they wish to implement and design their unique opera scenes. The following exemplifies how GSO may function in a specific location: during the preparations of the space-inspired opera "Unfold the Universe", a Norwegian primary school collaborated with an American rap artist and music educator in order to develop a rap music contribution to the opera. Both teachers and students took part in the performance of this music, which was then shared with all other GSO teams, worldwide during the opera's premier on November 20th, World Children's Day.

GSO was described as a signature pedagogy by Straksiene et al. (2022). Signature pedagogies according to Shulman (2005) are "types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions" (p. 52). The aim of our analysis and discussion is to explore to what extent it is possible to argue for a common and shared rationale, as well as a shared basis of educational design principles, for both science and arts education within that same signature pedagogy, and what that might imply for its educational design. Signature pedagogies are used in professional education as they contribute to formation of complex professional knowledge, skills, and moral understandings (Shulman, 2005). Contextualizing our analysis and discussion in the signature pedagogy supports an argument for the approach we present in this article, as a new rationale for STEAM education. To achieve this, we begin by detailing the educational design (Akkerman et al., 2011) of an already established approach to conceptualizing pedagogic principles and educational objectives which originated in a science education context (Sotiriou, 2013; Sotiriou et al., 2017). Then, we rely on the notion of comparative didactology (Nielsen, 2005), which provides a way of understanding didactics of teaching across disciplinary boundaries, to support our venture into arts education. Specifically, we rely on arts education literature (Dewey, 1934; Eisner, 2002; Winner et al., 2013) in order to formulate arts education pedagogic principles and educational objectives based on the original science education ones. These are developed within the same STEAM education environment, GSO. Finally, in order to ensure a two-way dialogue between the disciplines, we further develop the original science education pedagogic principles and educational objectives as a response to the ones we developed in arts education.

We thus observe, study, understand and further develop the various disciplines through each other's viewpoints. This is congruent with the concept of Janus (DiLorenzo, 2001; Taylor, 2000). Descriptions of the two-headed Janus specify the looking in two directions at once, as Janus's main characteristic. Indeed, Janus has been referred to as a literary allusion in which one text, "glancing" at another, directs the reader to two texts simultaneously (DiLorenzo, 2001). Janus has also been referred to as a differentiation based on a perspective of time, in which one face is looking to the future, the other to the past (Taylor, 2000). For us, Janus is a way of explaining the common dimensions of science and arts education, with mutual entry points to both, in a double perspective equilibrium (Klein, 2006), enabling multiple perspectives on the same focus of attention. Our discussion focuses on potential implications that this conceptual approach may have for the teaching profession in the context of STEAM education, and transdisciplinary education more generally.

2. Science education pedagogic principles and objectives

Science education requires development of a range of interests, attitudes, knowledge, and competencies (Sotiriou et al., 2017). Learning "facts" or how to design simple experiments do not suffice. In order to capture the multifaceted nature of science learning, several European science education projects, such as the Cosmos (2008), provided approaches for design and implementation of STEM activities which involve students in research and innovation processes, and articulated scientific capabilities which require support from both the school and informal learning environments outside of the school (Sotiriou, 2013). These provided an important foundation for the development of several STEAM education projects which the authors led (or participated in), in recent years.[5]

The "Global Science Opera Leverage students' participation and engagement in science through art practices" (GSO4SCHOOL) project (Robberstad et al., 2019; Sotiriou et al., 2021) was instrumental for our development of the transdisciplinary model described in this article. That project implemented educational activities across boundaries of science and arts within the context of the GSO, in a design

thinking framework[6] (Design Council, 2023). It achieved this by promoting cross-sectoral collaboration (teachers, students, young researchers, artists, creative industries) and professional development for (mainly European) GSO-active teachers (Sotiriou et al., 2021). GSO4SCHOOL's framework promoted acquisition of 21st century skills (including social and emotional intelligence skills, teamwork, critical thinking, creativity, soft skills and entrepreneurial skills) (OECD, 2015), science (analytical thinking, inquiry-based learning) and culture and the arts (performing arts of the disciplines music, drama, visual arts). Aiming for a shift in national policies in schools in the project countries (Norway, Cyprus, Greece, Portugal, Italy), GSO4SCHOOL worked on the following levels of the educational world (Robberstad et al., 2019; Sotiriou et al., 2021): school level, classroom level, the teacher's level, and the student's level. It was thus an empirical field in which the GSO signature pedagogy was implemented and further developed.

In this article, we take the six pedagogic principles and educational objectives used in the GSO4SCHOOL project, as a starting point for our work (Sotiriou et al., 2019).[7] These six strands of pedagogic principles and educational objectives, describe what students do when they learn science, reflecting the practical as well as the more abstract, conceptual, and reflective aspects of science learning. The six strands also represent important outcomes of science learning (Sotiriou, 2013). They encompass the knowledge, skills, attitudes, and habits of mind demonstrated by learners proficient in science, and, as such, are important resources for guiding the design and development of educational activities for schools. The educational activities in which the principles and objectives were contextualized, were inquiry-based (Dewey, 1938; Rocard, 2007). Specifically, these inquiry-based approaches guided students through a series of phases of[8] the creation of a science opera (Ben-Horin, 2014b). We now expand in detail each of the six science education pedagogic principles and, in parentheses, the educational objectives.[9]

(1) Sparking Interest and Excitement (Experiencing excitement, interest, and motivation to learn about phenomena in the natural and physical world).

Motivation, curiosity, and a willingness to persevere during exploration of complex scientific concepts and procedures are important aspects of learning science. The emotional engagement involved with students' interest is central in thinking and learning, and in retaining and remembering information (OECD, 2015). Indeed, they are drivers of students' seeking out learning about a topic (Biesta & Burbules, 2003; Dewey, 1938).

(2) Understanding Scientific Content and Knowledge (Generating, understanding, remembering, and using concepts, explanations, arguments, models, and facts related to science).

Students generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science. They know, use, and interpret scientific explanations of the natural and physical world, understand interrelations between scientific concepts, and use them to build and critique scientific arguments. These tendencies rely on an ability to use the scientific knowledge in one's own life (Dewey, 1934).

(3) Engaging in Scientific Reasoning (Manipulating, testing, exploring, predicting, questioning, observing, analysing, and making sense of the natural and physical world).

Reasoning about evidence is required in order for students to be able to design and analyze investigations. This includes evaluating, constructing and defending arguments, based on evidence in both formal and informal environments. Students thus manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world and, consequently, begin to develop a deeper understanding of the world.

(4) Reflecting on Science (Reflecting on science as a way of knowing, including the processes, concepts and institutions of science. It also involves reflection on the learner's own process of understanding natural phenomena and the scientific explanations for them).

Science is a dynamic process, based on continuous evaluation of new evidence and reassessing past ideas. Students reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about natural phenomena. They need opportunities to learn about how scientific knowledge is constructed and how scientific work occurs: carrying out scientific investigations does not in and of itself automatically lead to an understanding of the nature of science. Instead, educational experiences must support that understanding explicitly (Biesta & Burbules, 2003; Dewey, 1934).

(5) Using the Tools and Language of Science (Participation in scientific activities and learning practices with others, using scientific language and tools).

Science is a social process, in which scientists with different areas of expertise collaborate to reach new insights. Participation in informal environments can help non- scientists develop appreciation for how scientists work together, and of the language and tools they use. By engaging in scientific activities, students acquire an understanding of the language of scientists and gain entry into the scientific community's culture.

(6) Identifying with the Scientific Enterprise (Coming to think of oneself as a science learner and developing an identity as someone who knows about, uses, and sometimes contributes to science).

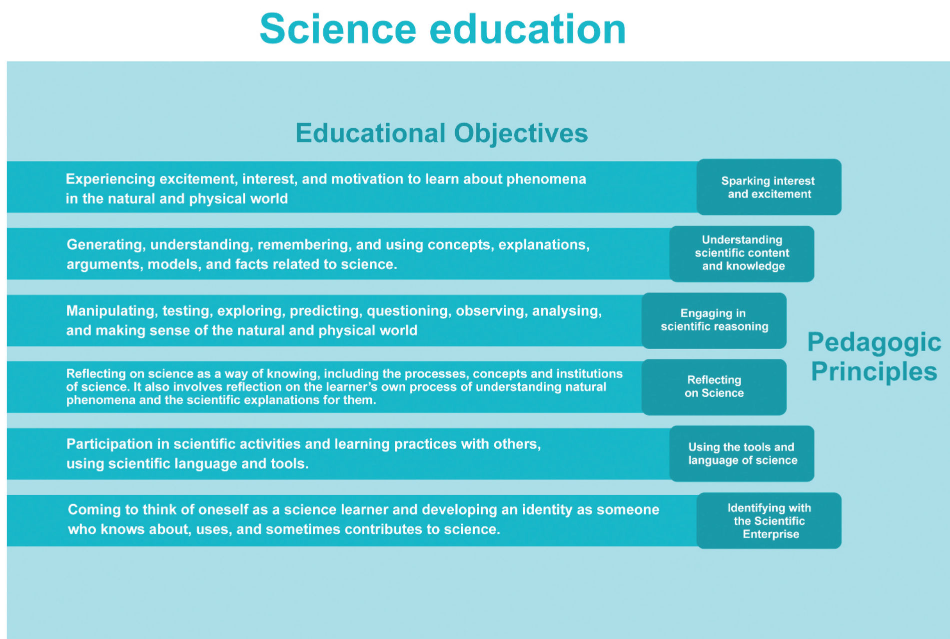
Through experiences in relevant educational programs, students may start to change the way they perceive themselves with regard to their relationships to science. They think about themselves as science learners and develop identities as persons who know about, use, and sometimes contribute to science. When this transformation occurs, young people may begin to think seriously about a career in scientific research. Indeed, changing individual perspectives about science is a far- reaching goal of outreach and educational activities of the major research infrastructures.

Figure 1 summarizes the proposed pedagogical principles and educational objectives for Science Education.

3. Arts education pedagogic principles and objectives

Arts education, like science education, requires development of various interests, attitudes, knowledge, and competences. Eisner (2002) specified the following amongst the main aims of arts education: the arts have value in and of themselves; arts education should instill pride in that

Figure 1. Science education pedagogic principles and educational objectives in a STEAM context (based on Sotiriou, 2013).



which is distinctive about the arts; arts education should help students learn how to create satisfying artistic outcomes,[10] how to see and respond to what we call arts, and how to understand relationships among the arts, as well as the roles they play in a society's culture; arts education should help students recognize what is personal and unique about themselves and the subtleties of their work; arts education should enable students to recognize and appreciate aesthetic forms of experience in everyday life and to cultivate habits of searching for and identifying aesthetic features in their surroundings (ibid, pg. 42–45). Indeed, students' intrinsic satisfaction and motivation during arts education depends on the artworks they create being part of their "everyday" lives[11] (Dewey, 1934, pg. 7–8). To achieve this, initiative for the educational transaction must be taken by the pupil (Dewey, 2012), thereby ensuring that education happens through experience and continuous interaction with his surroundings (Dewey, 1938).

In their report for the OECD, Winner et al. (2013) described arts education as: a means of developing critical and creative thinking; having the capacity to develop skills that enhance performance in other subjects (e.g. mathematics, science, reading and writing); potentially strengthening academic motivation, self-confidence, and ability to communicate and cooperate effectively; likely promoting reflection and metacognition when taught in environments which include students' evaluation of their own and peers' artworks, and reflection upon their processes of creating those works. Students enrolled in arts education courses display more ambition towards academic work and higher commitment and motivation levels; enhanced empathy, perspective taking, and emotion regulation (especially in education in dramatic art).[12] These tendencies would be consistent with arts education's leading to heightened student motivation (ibid).

In this section, we rely on texts by Eisner (2002), Dewey (1934, 1938, 2012) and Winner et al. (2013), as well as on our own experiences with STEAM education initiatives whose goals were first and foremost in the area of arts education,[13] to provide a rationale for arts education pedagogic principles and educational objectives in the STEAM education context. Our approach is rooted in a thinking we describe as comparative didactology, coined by Nielsen (2005). Didactology (Nielsen, 2005) serves as a scientific discipline in education in much the same way as musicology is understood as the scientific discipline in music. By describing and reflecting on art and science within a tradition of comparative didactology (ibid), we are focusing on the rationale, objectives and educational principles underpinning science-art integration in schools.

We now introduce six pedagogic principles and objectives within arts education in a STEAM context. These are based on arts education sources (Dewey, 1934, 1938, 2012; Eisner, 2002; Winner et al., 2013), and, in accordance with comparative didactology, are inspired by the science education pedagogic principles and objectives described in section 2.

(1) Sparking interest and excitement (To experience excitement, interest and motivation to learn about artistic environments and artistic expression). Motivation in education relies on students' own intrinsic satisfaction (Dewey, 1934), in all disciplines, including arts education, and arts education can strengthen motivation in other disciplines (Winner et al., 2013). Learning about artistic environments is important in and of itself, beyond the arts' contributions in other disciplines (ibid; Eisner, 2002).

(2) Facilitating understanding through and of artistic expression and knowledge (To generate artistic understanding by taking part in creative artistic processes, using concepts, explanations, arguments, models, works and facts related to the arts).

In the development of an arts education principle and objective, we have chosen to focus on the facilitation of understanding as being intertwined with artistic practices (Borgdorff, 2012). The arts education objective specifies how, and by which means, understanding is generated by the student. (The facts specified are related to the arts, for the sake of clarity in our conceptual discussion. A STEAM environment must, however, include facts about all related disciplines as an objective for arts education).

(3) Engaging in artistic reasoning and production (To explore, question, imagine, improvise, create, rehearse, observe, analyse and make sense of artistic processes and works.)

Artistic reasoning resonates with, and is detailed in, the rationale elements presented above (Eisner, 2002). However, the arts education objective deviates from the science education objective in its ways of making sense, and of what is being made sense of (namely, the artistic processes and the artistic works which represent the tangible end results of those processes).

(4) Reflecting on the particulars, effects and importance of the arts (To reflect on the arts as ways of knowing about the world, others and oneself, including the processes, concepts and institutions of the arts.)

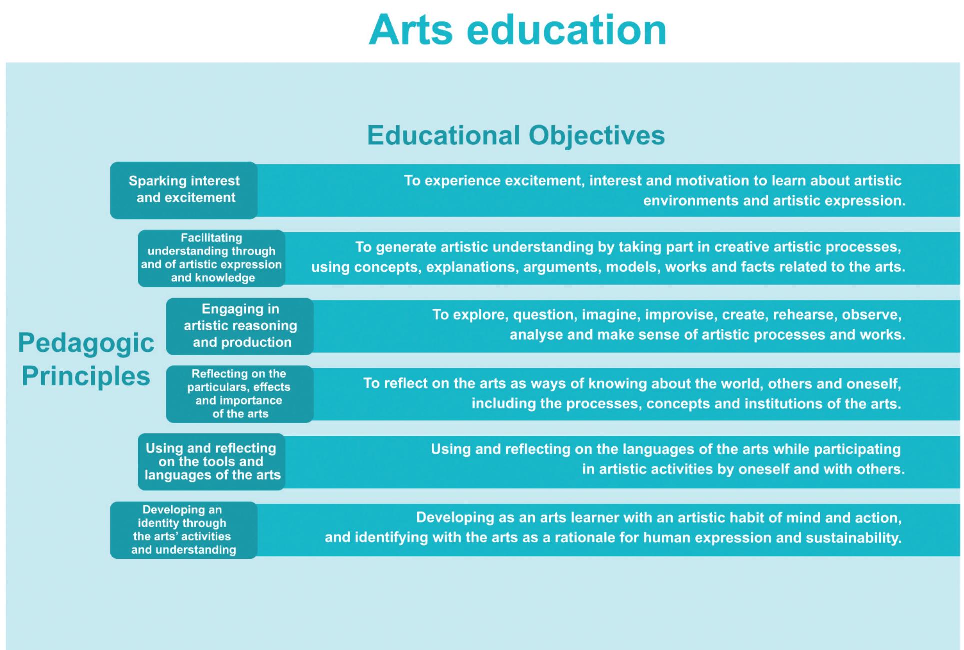
The process undergone by students is specified as relating to, and effecting, their experience (Dewey, 1934). This acknowledges a process undergone by students as one which involves "thinking in, through, and with art" (Borgdorff, 2012, pg. 143).

(5) Using and reflecting on the tools and languages of the arts (Using and reflecting on the language of the arts while participating in artistic activities by oneself and with others.)

The pedagogic principle resonates with a rationale for arts education, but we choose to pluralize languages, to accommodate for the unique characters and creativities (Burnard, 2012) at the core of different artistic practices. We perceive reflection to be an important element in the arts education pedagogical principle, as well as in the objective for the student's educational process (Eisner, 2002).

(6) Developing an identity through the arts (Developing as an arts learner with an artistic habit of mind and action, and identifying with the arts as a rationale for human expression and sustainability.)

Figure 2. Arts education pedagogic principles and educational objectives in a STEAM context.



While the science education objective is formulated in a way that can be directly appropriated for the arts, we omit the word "sometimes" in recognition of Dewey's (1934) concept of experience in education, something which is available for all, as a continuous and necessary element in a creative educational process. The pedagogical principle has been changed. Namely, the identification relates to one's own identity, rather than with an overall enterprise.

Figure 2 summarizes the proposed pedagogical principles and educational objectives for Arts education

4. The transdisciplinary "Janus" approach for integrated science-arts practices in education

The GSO signature pedagogy focuses on integration of arts and science in education. Integration, though, may be realized in a wide array of approaches, including those in which one discipline is conceived of as being in the service of another. In this article, we aim to provide grounds for the balancing of arts education and science education by allowing them to exist in equilibrium (Klein, 2006). Bresler (2002) describes this as a "co-equal" integration of disciplines (pg. 21), which we understand as being congruent with a notion of transdisciplinarity as the greatest degree of integration, in which discipline integration is itself the purpose (Ben-Horin, 2021; Klein, 2006). This, in turn, relies on understandings and goals beyond those confined to any single discipline being achieved. Indeed, social and innovative processes in an educational practice which transcends all five STEAM disciplines have been conceptualized and implemented by Liao (2016), who proposed the specification of conceptual spaces between and across all five disciplines, as well as beyond all disciplines. However, Liao (ibid) stops short of detailing pedagogic principles and educational objectives for the various disciplines which are part of her practice, something which we provide grounds for in this article. Also, while Liao (ibid) acknowledges transdisciplinarity's global dimension as an opportunity, she does not provide details about how STEAM practices could be implemented globally. During our work with GSO (2014-present) we have harnessed transdisciplinarity's global dimension. It is this global dimension which represents the understandings and goals which lie beyond the confines of any single discipline, and which makes the need for a combined transdisciplinary model and approach so pertinent for us as educators.

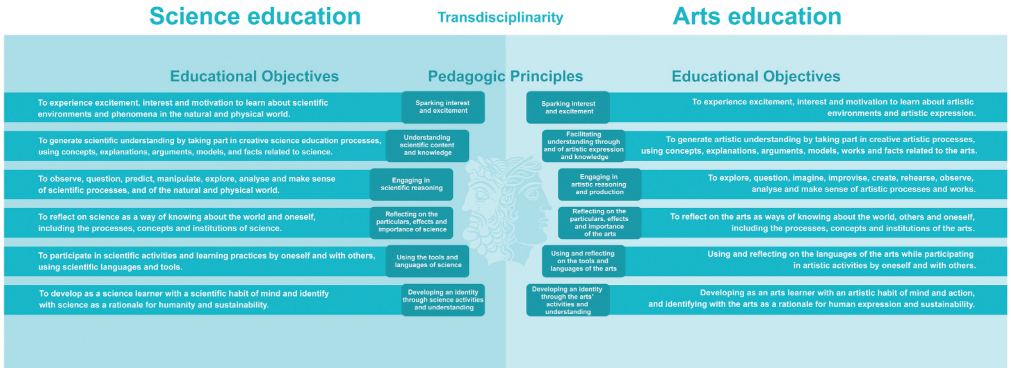


Figure 3. Combined Janus approach to pedagogic principles and educational objectives in arts and science education.

Science and the arts differ in many ways, though many of their inter-relationships have been described in detail by Ben-Horin (2015), Strosberg (2015) and Garoian and Mathews (1996). Some examples of such inter-relationships are their mutual reliance on idea generation; artworks which have scientific value; scientific phenomena which can be understood as having artistic value; persons who worked across the boundaries of science and art; collaborations between scientists and artists; themes (such as nature, light, astronomy) which have provided inspiration for scientific and artistic work (Strosberg, 2015). In the world of education, too, the integration of sciences and the arts displays similarities between them. But it also reveals tensions and differences (Colucci-Gray et al., 2017). This paradox leads us to the metaphor of the two-faced Janus approach: the Janus faces allow for difference while both faces are equally important parts of the whole. This provides inspiration for how various disciplines may co-exist in a single, unified understanding of knowledge (Dewey, 2012) in a STEAM education environment. In Figure 3, we demonstrate integration of the science and arts disciplines following the Janus approach by describing the transdisciplinary process in which the original science education principles and objectives (Sotiriou, 2013; Sotiriou et al., 2019), are now further developed as a consequence of the newly developed arts education ones. Figure 3 is followed by reasonings for why the pedagogic principles and educational objectives were formulated as they were. Those reasonings (1–6) correspond to the six strands of pedagogic principles and educational objectives as they are presented in Figure 3.[14]

Reasoning for strand 1: The principle "sparking interest and excitement" has a twofold function in both disciplines; first by being used to elicit students' curiosity and wonder, and second as illustrations of the scientific and artistic themes which provide the focus of experience and learning during each unique implementation of STEAM educational environments. In the arts, sparking interest and excitement is also a vital part of the artistic expression. *Reasoning for strand 2*: In both disciplines, activation and experience is crucial for the creation of understanding. Students' processes and their active thinking of and manipulation of artefacts and cultural objects may differ in line with specific assignments given. Likewise in science, students' processes and active thinking may differ in line with the concepts, explanations, arguments, models, and facts which provide the focus of specific assignments given. Indeed, in many cases artefacts, both cultural and physical, can be approached scientifically as well as artistically. *Reasoning for strand 3*: In contrast to science, the arts are often associated with feeling. This dualistic myth often conceals the fact that different forms of reasoning, artistic and scientific, are natural ingredients of a transdisciplinary science-arts pedagogy. Still, the arts have a special role in education with regard to the expression of feeling. *Reasoning for strand 4*: Reflection is a vital part of all educational processes. However, there are different forms of reflection. It is common to think of reflection as being verbal, but it can also be (as examples) musical, tactile or pictorial. *Reasoning for strand 5*: These objectives are closely linked to activation and reasoning in both disciplines, but the use of tools and language are very different in the arts and science worlds. However, used as part of a Janus pedagogy, that use will strengthen any educational enterprise. *Reasoning for strand 6*: We can form and have different identities in different contexts and times (Phinney & Baldelomar, 2011). A major intention of a transdisciplinary science-art pedagogy should therefore be to enhance not one, but multiple types of identities. A student may therefore simultaneously identify with science and with the arts, as rationales for experiencing and understanding the world.

5. Discussion

We are framing our discussion in three main themes: (1) the teachers' roles in the transdisciplinary STEAM education context, (2) knowledge creation across disciplinary boundaries, and (3) student identities in the transdisciplinary STEAM education context.

5.1. Teachers' roles in the transdisciplinary STEAM education context

The common origins of science and the arts support the notion that it is possible to spark students' interest in both disciplines at the same time. Both originated from rituals of everyday lives (Garoian & Mathews, 1996, pg. 193). The impulses to explore, imagine, be curious, be creative, understand, innovate, and express ourselves are common to both (Garoian & Mathews, 1996), and multiple examples exist of artworks which are also scientific instruments (Strosberg, 2015, pg. 235). Simultaneous onset of inquiry in the arts and science will, however, have consequences for roles of teachers and students in the educational process (Klein, 2006). The Janus approach thus raises questions about how paradigms of science and the arts in education affect each other on an epistemological level, as it will require reconceptualizing teachers as "generalists" or "connection experts" in addition to their specializations in one or more disciplines (Clarke and Agne, in Klein, 2006, pg. 7). While traditional schooling inducts students into disciplinary forms yet rarely allows students to experience connections between them (Colucci-Gray et al., 2017, pg. 35), the Janus approach offers a pedagogy of integration (Bresler, 2002) and synthesis (Klein, 2006). As a consequence, it will also create teaching situations in which teachers must relinquish at least partial control over their own expertise and knowledge (Ben-Horin et al., 2017; Biesta, 2015; Holdhus et al., 2016), to their colleagues in other disciplines, students, and to society at large.

5.2. Knowledge creation across disciplinary boundaries

Traditional STEM education has been described as harboring a western, rationalistic tradition of knowing, and been critiqued for being exclusive of other ways of knowing (Colucci-Gray et al., 2017, pg. 23). Scientific language is often perceived as being limited to discursive, mathematical forms, while the arts' languages are non-discursive and characterized by having sensory forms (Garoian & Mathews, 1996, pg. 194). The Janus approach contributes to exploration of languages' functioning across disciplinary lines, facilitating a framework for knowledge creation characterized by dynamic responsiveness to real-life conditions in which that knowledge is created (Colucci-Gray et al., 2017; Sotiriou et al., 2019), by transcending disciplines. In this process, the arts offer particular pathways to articulation and processing of experience[15] (Dewey, 1934), which can support a desirable change in perceptions of STEM under[16] condition that the arts and STEM are on equal footing (Bresler, 2002). The use of an art form as a "tool" in the "service of" another discipline should not be the goal in STEAM (Ben-Horin, 2021; Bresler, 2002; Mejias et al., 2021). Likewise, simply using a scientific fact as inspiration for an arts class does not suffice without action being taken to ensure a process of knowledge creation across the disciplinary boundaries, in which the different disciplines open gateways to each other. Thus, our provision of a set of combined, closely related pedagogic principles and educational objectives provides a much-needed conceptual framework which can benefit the epistemological and practical dimensions of the emerging field of STEAM education. A particular case of this, GSO enables teachers' and students' approaching and handling of "wicked problems" (Rittel & Webber, 1973) and uncertain environments which require both a global dimension of practice[17] (Ben-Horin, 2021), and that disciplines be transcended for the sake of a new vision of nature and reality (Bernstein, 2015). Seamless interaction with the practice field of schools (Kunnskapsdepartementet, 2014), and methods of research and practice

Involving all societal stakeholders (McKenney & Reeves, 2012; Sotiriou et al., 2017), are needed to achieve this. Students and teachers in GSO co-create knowledge and content with their peers in other schools, age groups, countries and cultural traditions. This requires employers, arts and science practitioners, teachers, educators and academics to communicate together and continuously exchange ideas about their respective work (Colucci-Gray et al., 2017, pg. 12). Students' reasoning is thus done across several kinds of boundaries simultaneously in GSO, and the Janus approach provides understanding of how pedagogic principles and educational objectives may co- exist and influence each other. While we have argued for similarities and common impulses of science and the arts, their physical products do generally differentiate in form, material and emotional interaction with their audiences (Garoian & Mathews, 1996). Enacting the educational process across that divide is neither easy nor straight-forward (Ben-Horin et al., 2017), and requires simultaneous reasoning within the terminologies, languages, tools and materials of more than one discipline. Each student must, in addition to group-related processes, engage in his own subjective reasoning to successfully participate in the Janus approach.

5.3. Student identities in the transdisciplinary STEAM education context

Multiple identities can be formed in different contexts and times (Phinney & Baldelomar, 2011). A transdisciplinary science-art pedagogy of synthesis can enable students' and teachers' formation of multiple types of identities. First, through their identification with both science and the arts, while adhering to distinct processes and products of each discipline. Such identification is not an easy task as it requires each student to find her own pathway to observing and implementing common ideas across the disciplinary boundaries. However, empirical studies have shown that, while challenging for both students and teachers, participating students found their unique ways of achieving this when provided with flexible frameworks by their teachers with regard to scheduling and choice of specific tasks in the opera production (Ben-Horin et al., 2017). Second, as academic "achievers" in the STEM and arts disciplines themselves. Achievement levels in STEM education may vary for different populations. Under-representation in STEM (with regard to both achievement in schools and career choices) as a consequence of gender or socio-economic status has been documented by Rocard (2007) who called for reconsideration of STEM content as a response to these challenges. Integrating educational practices more common in arts education, has potential to motivate participation of students who tend to favor the arts and humanities rather than STEM (Colucci-Gray et al., 2017; Craft et al., 2016). Furthermore, teachers have reported students' greater capability to retain information (Ben-Horin et al., 2017), and a stronger capability of synthesizing learning into a meaningful whole as a result of inter-connectedness of disciplines (Klein, 2006). Third, STEAM education's capacity to support broader educative agendas such as the strengthening of students' sense of empowerment (Colucci-Gray et al., 2017) is evident in the distinct student-teacher relations which arise during the improvisational aspects of working across disciplines (Ben-Horin & Boylan, 2016), and the development of students' identities as co-creators of the emergent curriculum. Empowerment is also evident in the formation of identities of groups of students following participation in GSO and those students' experiences with being part of the global community it is constituted of (Urbaniak, Venkatesh, and Ben-Horin, 2021). Fourth, identifying with a global dimension of other cultures and countries. Thus, the Janus approach enables development of identities in several areas of what it means to be human, and a rationale for sustainability. Extending students' collaborative identities in the social, intellectual, and emotional domains to become global learners and creators of knowledge across disciplinary boundaries provides them with the tools and credo for taking responsibility (Stilgoe et al., 2013) for their learning process, their peers, and their surroundings.

6. Conclusion

In this article, we conceptualized a combined set of pedagogic principles and educational objectives in both science and arts education within a STEAM education environment. That environment was the signature pedagogy Global Science Opera. We based this process of conceptualization on our own previous work with the development, implementation and research realized in the context of a portfolio of STEAM projects. We thus applied nuanced knowledge to our development of arts education pedagogic principles and educational objectives based on previously existing ones in the field of science education. We then revised the original science education principles and objectives in dialogue with the newly formulated ones in arts education. Our process was designed to ensure dialogic interaction between the disciplines' practitioners, thus achieving an equilibrium in which no discipline exercises power over the other (Mejias et al., 2021). Rather, our approach allows practitioners and school pupils to (metaphorically) see each discipline through the other, thus inspiring us to characterize the resulting conceptual model as a Janus (DiLorenzo, 2001; Taylor, 2000).

The European Commission has in recent years established numerous educational initiatives which have the crossing of disciplinary boundaries as their focal point. These initiatives have emerged within science, math, arts, creativity and general education, among others. Teachers' involvement in STEAM programs (Craft et al., 2016; Robberstad et al., 2019; Sotiriou et al., 2019) may be taxing and resource-intensive. However, participation seems to enable several opportunities and advantages for those teachers and their students (Ben-Horin, 2021; Ben-Horin et al., 2017; Robberstad et al., 2019; Sotiriou et al., 2019). These include possibilities for exchanging practices with peers in other countries; training for education which crosses disciplinary boundaries together with those peers; familiarization with other countries' curricula and educational structures; a deeper understanding of different cultures. Furthermore, participating students become recipients of up-to-date knowledge in the international field, as well as active contributors to the emergence of new knowledge in that field.

An integration pedagogy must be practiced in ways that ensure that objectives of all disciplines are being met with equal levels of respect (Bresler, 2002). A transdisciplinary approach therefore requires attentiveness to discipline-specific arguments as a prerequisite for engagements across disciplinary boundaries (Barad, 2007). Those engagements entail a reworking of disciplinary boundaries and, therefore, change for the involved teachers and students, as well as for the pedagogical principles and objectives which are implemented by teachers of those disciplines. We have exemplified this with a comparative didactology (Nielsen, 2005) in which arts education principles and objectives were developed by first relying on previously-existing science education principles and objectives (Sotiriou, 2013; Sotiriou et al., 2019), and then proposing revisions of the original science education principles and objectives based on the newly-developed arts education ones. This two-stage process was realized as such for the sake of a transdisciplinary educational environment which embodies the crucial roles that the material, discursive, natural and cultural elements all play in the creation of knowledge, regardless of discipline. These elements will always be in continuous movement and development (Dewey, 1934). The pedagogic principles and educational objectives formulated in this article are consequently proposed with a sense of humbleness regarding each and every student's being able to, or indeed, needing to achieve them all in every implementation of a STEAM educational environment.

While we have not provided an analysis of empirical material in this article, our credibility is anchored in our practical experience with GSO and other STEAM environments; our previous analyses of relevant empirical data in other contexts (Ben-Horin et al., 2017; Chappell et al., 2019); and in our didactic training materials for teachers, all of which were tailor-made for the practice field (Ben-Horin, 2014b; Robberstad et al., 2019; Sotiriou et al., 2019). Realizing the proposed pedagogic principles, and reaching the proposed educational objectives in the practice field, will require a detailed methodology of implementation. Hence, we recommend that future empirical research be conducted on the interactions of the proposed transdisciplinary Janus approach and (a) Design Thinking methodology (Design Council, 2023), and (b) Open Schooling (Sotiriou et al., 2017).

Our credibility is, furthermore, strengthened by the fact that we are well-rehearsed with intentions for transdisciplinarity. Science education initiatives with which GSO interacts (e.g. Open Schools for Open Societies (OSOS)) implements a transdisciplinary approach in the balancing of teaching and educational objectives of all STEM disciplines. Similarly, the arts education methodology Write an Opera (Griffiths, 2012), on which much of GSO's approach to art-making is based, integrates various arts education disciplines in a balanced way, allowing for educational objectives to be achieved in music, drama, and visual arts simultaneously. The Janus approach conceptualizes transdisciplinarity within a unified process across the boundaries of arts and science. We therefore encourage the educational community to employ the Janus model as a way of achieving transdisciplinary educational environments which respect the pedagogic principles and educational objectives of all disciplines involved in the STEAM education environment.

The arguments we have provided do not in themselves guarantee a meaningful implementation of STEAM education in schools (McKenney & Reeves, 2012; Peirce, 1878). We are cautious about the possibility of "guaranteeing and securing" transdisciplinarity. Transdisciplinarity may ultimately function as an ideal towards which educational programs may aim, while reaching its purest form is not guaranteed due to the complexity of anchoring it in real-life programs which require financial, logistical, and other issues to be handled as part of its implementation (Ben-Horin, 2021). Teachers need to continuously strive towards an equilibrium between disciplines, which must be negotiated anew at each step of the educational process. Thus, our final conceptual diagram (Figure 4) has the figure of a bird as its heart. The bird is a metaphor for GSO as a transdisciplinary environment. Singing, which many birds do as a foundational element of their nature, is also a vital element in opera. Birds embody movement during flight, and when they interact with their surroundings. As in the risky transdisciplinary educational environment, we can never truly know how many, or which, movements a bird will make: we cannot always foresee the direction of its flight. Birds also exemplify a natural phenomenon which has provided inspiration for both art and science (Strosberg, 2015), and which can elicit curiosity and wonder in educational settings. The bird is thus a fitting focus for creative attention in a transdisciplinary environment which must be kept in equilibrium by means of its practitioners' exploring and experiencing science as a gateway to the arts and vice versa.

Figure 4. Conceptual diagram.

Acknowledgments
The authors wish to thank the consortia in the projects referenced in this article, as well as the participants of the Global Science Opera. The authors wish to thank Mauricio Esteban Pavez Ramirez (Media Lab, Western Norway University of Applied Sciences) for the graphics in diagrams 1-4.

Funding
The work was supported by the Høgskulen på Vestlandet.

Author details
Oded Ben-Horin[1]
E-mail: oded.ben@hvl.no
ORCID ID: http://orcid.org/0000-0002-8658-0768
Menelaos Sotiriou[2]
ORCID ID: http://orcid.org/0000-0001-6252-297X
Magne Espeland[1]
ORCID ID: http://orcid.org/0000-0002-3706-4281
Giedrė Strakšienė[3]
ORCID ID: http://orcid.org/0000-0001-8533-0276
[1] Department of Arts Education, Western Norway University of Applied Sciences, Stord, Norway.
[2] Science View, Athens, Greece.
[3] Faculty of Social Sciences, Western Norway University of Applied Sciences and Klaipeda University, Klaipeda, Lithuania.

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

Supplementary data
Supplemental data for this article can be accessed online at https://doi.org/10.1080/2331186X.2023.2287895

Citation information
Cite this article as: Towards transdisciplinarity in global integrated science-arts practices in education? A Janus approach, Oded Ben-Horin, Menelaos Sotiriou, Magne Espeland & Giedrė Strakšienė, *Cogent Education* (2023), 10: 2287895.

Notes

1. The term “discipline” (from the latin disciplina) originally indicated an educational setting and instruction of disciples.
2. The concept of transdisciplinarity emerged in the 1970’s, in critique of knowledge arranged in disciplines, including in relation to design and structure of educational programs. Since then, transdisciplinarity has been applied to complex, global challenges (e.g. a changing climate, and social problems and educational systems’ designs) (Bernstein, 2015; Liao, 2016).
3. Science education and STEM education overlap, yet they are not entirely synonymous. The educational literature contains examples of science education as one of four STEM disciplines, as well as examples of “science education” being invoked as an overall representation for all STEM disciplines. Throughout this article, we have used terms as they appeared in the various literary sources on which we relied.
4. The authors report that there are no competing interests to declare.
5. The authors have been active in several STEAM initiatives which developed parallel to, shortly after, or as a direct consequence of the GSO’s establishment. Examples of these, whose goals were first and foremost in the area of science education, are Implementing Creative Strategies Into Science Teaching (CREAT-IT) (Craft et al., 2016); Creativity, Arts and Science in Primary Education (CASE) (Sotiriou et al., 2019); Developing an Engaging Science Classroom (CREATIONS) (Chappell et al., 2019); The Global Science Opera Leverage students’ participation and engagement in science through art practices (GSO4SCHOOL) (Robberstad et al., 2019; Sotiriou et al., 2021). The various projects included different representatives of the team of authors.
6. Design Thinking (Design Council, 2023) is a design methodology that provides a solution-based approach to solving problems that are unknown, re-framing those problem in human-centric ways by generating ideas during brainstorming sessions, and by hands-on approaches to prototyping and testing of those prototypes. Design Thinking methodology was employed and further developed by the Open Schools for Open Societies (OSOS) project and its corresponding Open Schooling Model (Sotiriou et al., 2017). These were later integrated in European STEAM projects (e.g. NEXT STEP, 2022; Robberstad et al., 2019; Sotiriou et al., 2019) with the aim of introducing innovative and entrepreneurial dimensions into the science and art disciplines in formal, informal and non-formal settings. By following a didactic approach based on the notion of “ideas become reality”, an understanding of and contribution to the further development of the educational setting’s “openness” was achieved (Sotiriou et al., 2017).
7. These strands build upon an earlier 4-strand model, developed to describe science learning in school setting (National Research Council, 2007, which was extended to six to incorporate informal science learning approaches in the model, and specifically a commitment to interest, personal growth, and sustained engagement (see for example Lazoudis et al., 2013).
8. These phases of an inquiry-based process were originally developed by the Cosmos (2008): Question Eliciting Activities/Exhibiting Curiosity; Active Investigation; Creation; Discussion; Reflection.
9. See Sotiriou et al. (2019) and Lazoudis et al. (2013) for further detail about these principles and objectives.
10. Eisner’s (2002) perspective emerged from the visual arts. He thus specified satisfying visual images as an aim for arts education. In this article, however, we are working with the concept of arts education in general, rather than with any single art form. Eisner’s starting point in visual arts is thus extended to support a more general rationale for arts education.
11. Dewey (1934) critiqued the creation and collection of artworks which are segregated from everyday life (pg. 7–8) for their being “specimens of fine art and nothing else” (ibid, pg. 8) rather than results of an aesthetic process in experience.
12. Winner et al. (2013) specify for several of these claims that they are highly likely, but still in need of further research before being characterized as confirmed.
13. Write a Science Opera (WASO) (Sousa et al., 2016) and ART@CREATIONS (Western Norway University of Applied Sciences, 2018).
14. Reasonings 1–6 correspond to the strands in a top-down order. Reasoning 1 corresponds to the strand

with the pedagogic principle "Sparking interest and excitement", etc.

15. A central feature of those pathways is the arts' tradition of understanding the body as a location of action-based knowledge formation (Colucci-Gray et al., 2017, pg. 38), and the body's essential role in our making sense of the world (Chappell et al., 2016).
16. The different STEM disciplines may have different relationships to art subjects in schools (Colucci-Gray et al., 2017, pg. 12).
17. Transdisciplinarity has been used to address so-called "wicked problems" (Rittel & Webber, 1973), which are ill-defined societal problems for which traditional "solutions" do not exist. "wicked problems" are too large and complex to be comprehensively addressed by practitioners of any single discipline, and approaching them requires a global dimension characteristic of transdisciplinarity (Bernstein, 2015). The "wicked problems" require creative solutions, simultaneously examining them from multiple angles. Those multiple angles, called upon to explore solutions to the complex global challenges in educational contexts, require corresponding global practices, pedagogies, and methods to which they can relate, and in which they can be implemented. GSO exemplifies a global context in which learners and teachers in various locations throughout the globe co-create knowledge together, as a global community of stakeholders regardless of nationality, age, salary, ethnicity, etc.

References

Akkerman, S. F., Bronkhorst, L. H., & Zitter, I. (2011). The complexity of educational design research. *International Journal of Methodology*, *47*(1), 421–439. https://doi.org/10.1007/s11135-011-9527-9

Barad, K. (2007). *Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning*. Duke University Press.

Ben-Horin, O. (2014a). SkyLight Opera [conference presentation]. *Astronomy Education Alliance Meeting 2014, Global Hands on Universe*. Cascais, Portugal.

Ben-Horin, O. (2014b). *The Write a Science Opera (WASO) Guidelines*. The CREAT-IT Comenius Multilateral Project.

Ben-Horin, O. (2015). The making of a neuroscience opera. In A. B. Reinertsen & A. M. Otterstad (Eds.), *Metodefestival og Øyeblikksrealisme* (pp. 241–252). Fagbokforlaget.

Ben-Horin, O. (2021, February 26) . *Educational Design Research and transdisciplinarity: The potentials and consequences for teachers and learners*. PhD dissertation trial lecture. University of Bergen.

Ben-Horin, O., & Boylan, M. (2016). Towards a professionalization of pedagogical improvisation in teacher education. *Cogent Education*, *3*(1), 1248186. https://doi.org/10.1080/2331186X.2016.1248186

Ben-Horin, O., Chappell, K. A., Halstead, J., Espeland, M., & Vaughan, T. (2017). Designing creative inter-disciplinary science and art interventions in schools: The case of Write A Science Opera (WASO). *Cogent Education*, 4(1), 1376926. https://doi.org/10.1080/2331186X.2017.1376926

Bernstein, J. H. (2015). Transdisciplinarity: A view of its origins, development and current issues. *Journal of Research Practice*, *11*(1), 1–20.

Biesta, G. J. J. (2015). *The beautiful risk of education*. Paradigm Publishers.

Biesta, G. J. J., & Burbules, N. C. (2003). *Pragmatism and educational research*. Rowman & Littlefield Publishers, Inc.

Borgdorff, H. A. (2012). *The conflict of the faculties. Perspectives in artistic research and academia*. Leiden University Repository. https://library.oapen.org/viewer/web/viewer.html?file=/bitstream/handle/20.500.12657/32887/595042.pdf?sequence=1&isAllowed=y

Bresler, L. (2002). Out of the trenches: The joys (and risks) of cross-disciplinary collaborations. *Council of Research in Music Education*, *152*(Spring), 17–39.

Burnard, P. (2012). *Musical creativities in practice*. Oxford University Press.

Chappell, K., Hetherington, L., Ruck Keene, H., Wren, H., Alexopoulos, A., Ben-Horin, O., Nikolopoulos, K., Robberstad, J., Sotiriou, S., & Bogner, F. X. (2019). Dialogue and materiality/embodiment in science/arts creative pedagogy: Their role and manifestation. *Thinking Skills and Creativity*, *31*, 296–322. https://doi.org/10.1016/j.tsc.2018.12.008

Chappell, K., Pender, T., Swinford, E., & Ford, K. (2016). Making and being made: Wise humanising creativity in interdisciplinary early years arts education. *International Journal of Early Years Education*, *24*(3), 254–278. https://doi.org/10.1080/09669760.2016.1162704

Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Gray, D., & Trowsdale, J. (2017). *Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st century learning: How can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?* https://www.bera.ac.uk/project/bera-research-commissions/reviewing-the-potential-and-challenges-of-developing-steam-education-

Cosmos. (2008). *The COSMOS project guided research modele*. Development of an Educational Scenario Template http://www.cosmosportal.eu/cosmos/files/help/COSMOS_Learning_Activities_Templates.pd

Craft, A., Ben-Horin, O., Sotiriou, M., Stergiopoulos, P., Sotiriou, S., Hennessy, S., & Conforto, G. (2016). CREAT-IT: Implementing creative strategies into science teaching. In M. Riopel & Z. Smyrnaiou (Eds.), *New developments in science and technology education* (pp. 163–179). Springer.

Design Council. (2023). *Council website*. www.designcouncil.org.uk/our-resources/the-double-diamond

Dewey, J. (1934). *Art as experience*. The Berkeley Publishing Group.

Dewey, J. (1938). *Experience and education*. Macmillan.

Dewey, J. (2012). *How we think*. Renaissance Classics.

DiLorenzo, K. M. (2001). Looking both ways: Janus, doubling, and intertextuality in Ovid. *Dissertations Available from ProQuest* https://repository.upenn.edu/dissertations/AAI30036

Eisner, E. (2002). *The arts and the creation of mind*. Yale University Press.

Garoian, C. R., & Mathews, J. D. (1996). A common impulse in art and science. *Leonardo*, *29*(3), 193–196. https://doi.org/10.2307/1576244

Global Science Opera. (2016). *Project website*. www.globalscienceopera.com.

Griffiths, H. (2012). *Write an Opera. Teachers' notes*. Royal Opera House and Den Norske Opera and Ballett.

Holdhus, K., Høisæter, S., Mæland, K., Vangsnes, V., Engelsen, K. S., Espeland, M., Espeland, Å., & Boylan, M. (2016). Improvisation in teaching and education—roots and applications. *Cogent Education*, *3*(1), 1204142. https://doi.org/10.1080/2331186X.2016.1204142

Klein, J. T. (2006). A platform for a shared discourse of interdisciplinary education. *Journal of Social Science Education*, *5*(4), 10–18.

Kunnskapsdepartementet. (2014). *Strategi: Lærerløftet*. På Lag for Kunnskapsskolen. https://www.regjeringen.no/globalassets/upload/kd/vedlegg/planer/kd_strategiskole_web.pd
Lazoudis, A., Sotiriou, S., & Sotiriou, M. (2013). *Discover the Cosmos EU project*. Discover The Cosmos portal: Guidelines for Developing Technology Enhanced Science Education Activities. http://portal.discoverthecosmos.eu/files/repository/DtC_manual.pdf
Liao, C. (2016). From interdisciplinary to transdisciplinary: An arts-integrated approach to STEAM education. *Art Education*, *69*(6), 44–49. https://doi.org/10.1080/00043125.2016.1224873
Marshall, J. (2014). Transdisciplinarity and art integration: Toward a new understanding of art-based learning across the curriculum. *Studies in Art Education*, *55*(2), 104–127. https://doi.org/10.1080/00393541.2014.11518922
McKenney, S., & Reeves, T. (2012). *Conducting educational design research*. Routledge.
Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., Roche, J., Wong, J., Hurley, M., Bell, P., & Bevan, B. (2021). The trouble with STEAM and why we use it anyway. *Science Education*, *105*(2), 209–231. https://doi.org/10.1002/sce.21605
National Research Council. (2007). Taking science to school: Learning and teaching science in grades K-8. Committee on science learning, kindergarten through eighth grade. In R. A. Duschl, H. A. Schweingruber, & A. W. Shouse (Eds.), *Board on science education, center for education, division of behavioral and social sciences and education* (pp. 36–41). The National Academies Press. https://doi.org/10.17226/11625
NEXT STEP. (2022). *Project website*. www.the-next-step.eu
Nielsen, F. V. (2005). Didactology as a field of theory and research in music education. *Philosophy of Music Education Review*, *13*(1), 5–19. https://doi.org/10.2979/PME.2005.13.1.5
OECD. (2015). *Skills for social progress: The power of social and emotional skills*. OECD Skills Studies, OECD Publishing. https://doi.org/10.1787/9789264226159-en
Peirce, C. S. (1878). How to make our ideas clear. *Popular Science Monthly*, *12*(January), 286–302.
Phinney, J. S., & Baldelomar, O. A. (2011). Identity development in multiple cultural contexts. In *Bridging cultural and developmental approaches to psychology: New syntheses in theory, research, and policy*. https://doi.org/10.1093/acprof:oso/9780195383430.003.0008
Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4(2), 155–159. https://doi.org/10.1007/BF01405730
Robberstad, I. J., Doran, P., Ben-Horin, O., & Sotiriou, M. (2019). GSO4SCHOOL project. *The GSO4SCHOOL Teachers' Guidelines*. http://gso4school.eu/wpcontent/uploads/2021/O2_D2_1/D2_1_GSO4SCHOOL_Teachers_Guidelines_Final.pdf.
Rocard, M. (2007). *Report of the high-level group on science education*. European Commission. http://ec.europa.eu/research/sciencesociety/document_library/pdf_06/report-rocardonscience- education_en.pdf
Shulman, L. S. (2005). Signature pedagogies in the professions. *Daedalus*, *134*(3), 52–59. https://doi.org/10.1162/0011526054622015
Sotiriou, S. (2013). *Effective ways of introducing eScience in schools Guidelines for developing Technology enhanced science education activities*. Deliverable D6.6 of the Discover the Cosmos EU Project. Available at: http://discoverthecosmos.eu/imported/public/english_DTC_ROADMAP13854820505.rar
Sotiriou, M., Ben-Horin, O., Smegen, I., Serogloou, F., Koulountzos, V., Sotiriou, S., & Alexopoulos, I. (2019). *Creativity, arts and science in Primary education – CASE toolkit*. Published by Science View. ISBN: 978-618-84415-0-7. https://www.researchgate.net/publication/334084029_Creativity_Arts_and_Science_in_Primary_Education_CASE_Toolkit.
Sotiriou, M., Ben-Horin, O., Stergiopoulos, P., & Robberstad, J. (2021). *The GSO4SCHOOL framework and master plan*. www.gso4school.eu
Sotiriou, S., Cherouvis, S., Mauer, M., Bogner, F. X., Bagiati, A., Sarma, S. E., Zygouritsas, N., Giannakopoulou, A., Mylopoulos, G., Fermeli, G., Kiriakidi, E., Van Laar, E. M., Guenaga, M., Verboon, F., Parente, R., DiMartino, F., Gaist, O., Bloch, N., Oron, E., & Ben- Horin, Y. (2017). Open Schooling model. *Deliverable D2.1 of the OSOS Project*. https://www.openschools.eu/wp-content/uploads/2018/01/D2.1-Open-Schooling-Model.pdf
Sotiriou, M., Robberstad, J., Ben-Horin, O., & Stergiopoulos, P. (2019). *The GSO4SCHOOL framework and master plan*. European Commission Erasmus+ program, the GSO4SCHOOL project. http://gso4school.eu/gso4school-framework/
Sousa, A., Ben-Horin, O., Ramos, A., & Lopes, A. (2016). Write a science Opera (WASO): Is there a motivational boost in multidisciplinarity and creativity? *New Perspectives in Science Education, 5 (Conference Proceedings)*. https://conference.pixel-online.net/NPSE/files/npse/ed0005/FP/2584-ESM1653-FP-NPSE5.pdf
Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a framework for responsible innovation. *Research Policy*, *42*(9), 1568–1580. https://doi.org/10.1016/j.respol.2013.05.008
Straksiene, G., Ben-Horin, O., Espeland, M., & Robberstad, J. I. (2022). Towards a rationale for science-art integration as a transdisciplinary signature pedagogy. *Cogent Education*, *9*(1). https://doi.org/10.1080/2331186X.2022.2087459
Strosberg, E. (2015). *Art and science* (2nd ed.). Abbeville Press.
Taylor, R. (2000). Watching the skies: Janus, auspication, and the shrine in the Roman Forum. *Memoirs of the American Academy in Rome*, *45*, 1. https://doi.org/10.2307/4238764
Urbaniak, K., Venkatesh, V., & Ben-Horin, O. (2021). A creative global science Classroom: Crafting the global science Opera. In K. Holdhus, R. Murphy, & M. Espeland (Eds.), *Music education as craft: Reframing theories and practices* (pp. 151–163). Springer.
Western Norway University of Applied Sciences. (2018). *The ART@CREATIONS project. Liebe Radioaktive Damen und Herren*. UH-NETTVEST. www.youtube.com/watch?v=WLkZX_vlSZE
Winner, E., Goldstein, T. R., & Vincent-Lancrin, S. (2013). *Arts and art`s for Sake? overview. The impact of arts education*. OECD Publishing. https://doi.org/10.1787/9789264180789-en
Yakman, G. (2008). STEAM education: An overview of creating a model of integrative education. *Pupils Attitudes Towards Technology 2008 Annual Proceedings*. The Netherlands. https://www.researchgate.net/publication/327351326_STEAM_Education_an_overview_of_creating_a_model_of_integrative_education