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Towards a rationale for science-art integration as a transdisciplinary signature pedagogy

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Abstract: The main aim of this paper is to address the increasing need for science-art integration across all levels of education globally. Specifically, the need to identify a signature pedagogy for the Global Science Opera (GSO) that can be used in teaching and learning contexts in formal and non-formal education. This part of the paper draws upon the seminal work of Lee Shulman (2005) to contemplate and propose a signature pedagogy for the GSO. Contemporary ideas from the science-art teaching and learning sources are also used to develop a sound pedagogical foundation for the approach advocated by the GSO. We argue that the development of a signature pedagogy for the GSO provides clarity around the challenge of

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developing a standard approach to teaching science through art activities. This paper presents the GSO practices that has the potential influence to reshape science teaching and learning process through art.

Subjects: Education; Educational Research; International & Comparative Education; Theory of Education

Keywords: Signature pedagogy; science-art integration; transdisciplinarity; education; students; GSO

The year is 2019. It is the centennial of the theory of general relativity. High school pupils from the African islands of Sao Tome and Principe are collaborating with Brazilian pupils to create a storyline for their scenes in a global opera production inspired by the scientific theme of gravity. Both Principe and the small town of Sobral in Brazil were crucial data-gathering locations during the creative process which led to the theory's proof. Now, as part of the centennial celebration, and specifically the "Eddington@Sundy" events, the pupils are taking inspiration from both the scientific process which led to the theory, and its outcomes, for a science-inspired opera titled "Gravity". Their creative process includes constant crossings of the boundaries between the disciplines of science and art. They interpret scientific questions from within drama. They must understand the scientific content and what they feel and reflect about it, before they can write the lines of the opera's main story. There is no "one size fits all" for this process, and it must be engaged with anew by each pupil, together with her peers.

Around the world, other student-groups, schools, universities, and art institutions are going through a similar creative process, creating their opera scenes through in-depth focus on various sub-topics of gravity. These scenes complement and complete the main story's historic re-enacted story-telling, showing how this fundamental scientific discovery influences our lives today. The final edit brings together the conglomerate of sub-topic-scenes into one cohesive story, before the opera premieres on November 20th, the UN's World Children Day. (From a Global Science Opera process[1]).

1. Introduction

In preparation for 2030, authorities argue that people should be able to think creatively, and to develop new products and services, jobs, ways of thinking and living, enterprises, sectors, business models and social models. Competences needed to achieve these include adaptability, creativity, curiosity and open-mindedness (OECD, 2018, p. 5). Innovation, however, springs not from individuals thinking and working alone, but through cooperation and collaboration with others to draw on existing knowledge, and to create new knowledge for a sustainable future. A focus on new priorities in education for the future brings researchers and practitioners face to face with fundamental questions: How to implement such priorities in practice? How should learning and teaching processes be organized to meet these priorities? What kind of pedagogies need to be applied in order to reach OECD aspirations and ambitions for education for sustainability in 2030?

Responses to new challenges often rely on integration of disciplines. They require the development of key competences for tomorrow's world (Winner et al., 2013, p. 4). These, in turn, rely on three sets of overlapping skills (technical skills, skills in thinking and creativity, and behavioural and social skills), and on educational systems' preparing students and young people for a continuously changing technological, globalized, interconnected world. This article consequently relies on research (Bresler, 2002; Gardner, 1983; Marshall, 2014; Liao, 2016; Burnard et al., 2021) which suggests that interaction between disciplines and their integration are effective ways of teaching and learning with regard to the above-mentioned overlapping skills.

In this article our example of integration-based teaching and learning is a Science-Arts pedagogy and practice, the Global Science Opera (GSO), from which the opening vignette is taken. Our article explores and discusses GSO as a signature pedagogy (Schulman, 2005a and 2005b) and specifically as a transdisciplinary one. Our discussion also includes limitations and challenges of discipline integration, e.g. when the science discipline is not in harmony with arts education aims or disconnected from the arts it seeks to interact with.

By reviewing research and theorising literature on signature pedagogies and GSO practices, this article explores two fundamental research questions:

RQ 1: What are the main elements of GSO practices and how can they be described and further developed as signature practices of science-art integration?

RQ 2: What characterize integrated science-art practices in GSO based on a transdisciplinary rationale and pedagogy?

Before discussing GSO pedagogy specifically, we reflect on our understanding of some basic concepts and key theoretical insights. The theoretical concepts are presented as a contribution to wider and continuing pedagogical dialogue between science and art educators. Indeed, it often remains unclear for educators what transdisciplinary education, in which science and art are integrated, actually entails for their daily teaching practice. Thus, some main concepts are presented below in relation to the two research questions outlined in this Introduction.

1.1. Science—art pedagogies and integration

The arts have often been understood as supporting development of human creativity (Gardner, 1983, 2006). The global need for methods which activate students in science teaching contexts has led to an increased application of the arts as a way of learning. Arts-based pedagogies are increasingly emphasised as significant for teaching generally in terms of improving students' learning outcomes, developing students' capabilities, and their motivation, communication, collaboration, and self-view (Fleming et al., 2015; Harland et al., 2000; Straksiene et al., 2009). An important argument for arts-based pedagogies is that every student learns on both personal and academic levels, something that they will also carry with them later in their professional and personal lives: as (Eisner, 2001, p. 369) wrote, it is what students do with what they learn when they can do what they want to do that is the real measure of educational achievement. Such views are also expressed by (Ghanbari, 2015) who argued that the arts have the ability to open up new ways of seeing, thinking, and learning through combining diverse elements into harmonious wholes with a synergistic result (Root-Root-Bernstein, 2015). Learning can thus be understood as knowledge acquisition through integrational procedures and creative activities.

Arts-integration is a complex term which does not have one universal meaning, as it encompasses different forms and modes. For (Silverstein & Layne, 2010), arts-integration is an approach to teaching and learning in which students construct and demonstrate understanding through an art form. Indeed, the way in which arts-integration is planned and performed can be an artistic process in itself (Burnaford et al., 2001). Arts-integration is widely used in schools, but has also been critiqued, e. g. regarding the widespread practice of including the arts as an "ornament" without ensuring substantially integrated practices. Critics argue that loss of learning might happen in cases of integration of arts and science without a clear concept of what integration means, as in the case of educational practices founded on the idea that children will learn about something, e. g. the moon and stars, by just singing songs about them. Arts-integration is often treated as "doing", rather than a way of "knowing", and constraints regarding time, space, materials, expectations, and comfort levels all present challenges when integrating the arts in other subjects.

In this article we argue that science-arts pedagogies need to be based on a transdisciplinary platform. We find support for this in the OECD document referred to above (Winner et al., 2013, p.12) which states that "researchers need to build stronger theoretical frameworks on why and how arts education can be hypothesised to develop certain skills which then transfer to other academic subjects".

1.2. Transdisciplinarity

An essential problem in understanding the role of integration in a transdisciplinary educational context stems from semantic differences and interpretations of "integration". Theories of curriculum integration are rooted in principles of progressivism and constructivism (Dewey) in which the main idea of education focuses on holistic development through the integration of academic disciplines, and where learning is understood as an active construction of meaning. *Integration* implies fusion of disciplines (Taylor et al., 2006). Art integration has been characterized as multidisciplinary, interdisciplinary, or transdisciplinary (Ulbricht, 2005). In general, the terms multidisciplinary, cross-disciplinary, interdisciplinary, and transdisciplinary are used to imply an increasing order and level of different degrees of synthesis and interaction. The combination of subjects may be process or content focused and that concepts such as multidisciplinary, plur-disciplinary, cross-disciplinarity, interdisciplinarity, and transdisciplinarity carry meanings that can clarify different levels of integrative approaches (Hope, 1995. Marshall, 2014, p. 105) notes that art integration comes in multiple forms, from approaches that employ simple illustration of academic topics to others that foster metacognitive skills.

Transdisciplinarity acknowledges component disciplines, highlighting the wisdom each discipline brings to the whole, seeing them in light of their commonalities. Transdisciplinarity combines disciplinary integrity with a holistic vision (Klein et al., 2001., 2001, p. 251) argue that "transdisciplinarity is best conceived as a cross-disciplinary methodology that organizes mutual learning and joint problem solving between science and society". Transdisciplinarity, then, implies that both the society's interests and the processes of science and art are in mutual balance.

In our view, what sets transdisciplinarity apart from other pedagogical rationales and what assures its role in twenty first century education, is its focus on the inherent complexity of reality that is seen when one examines a problem or phenomenon from multiple angles and dimensions with a view toward "discovering hidden connections between different disciplines" (Madni, 2007, p. 3). Transdisciplinarity refers to the establishment of a common system of axioms for a set of disciplines. We shall argue that a juxtaposition of science-art integration based on transdisciplinarity, coupled with descriptions and concepts of "signature pedagogies" described by Shulman (2005), offer a meaningful tool for this kind of conceptual description and analysis.

1.3. Signature pedagogies

Shulman (2005, p. 52) presents "signature pedagogies" as "the types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions". Signature pedagogies are widely used in professional education as they contribute to formation of complex professional knowledge, skills, and moral understandings. According to Schulman signature pedagogies are based on three dimensions: *surface, deep*, and *implicit* structures. A *surface structure* entails concrete acts of teaching and learning. It is that which is actually visible in the classroom and consists of the observable and behavioural features. A *deep structure* refers to imparting knowledge and skills to learners. It involves intentions, rationale, and theory. An *implicit structure* relates to moral values and beliefs about professional attitudes and dispositions. It enables focus on complex subject matters which, in turn, develop habits of mind relating to affective, cognitive and psychomotor learning aspects, such as involving students in performance, thus emphasizing their role as visible, active learners, and rendering the classroom space unpredictable and surprising (Shulman, 2005). Signature pedagogies contribute to forming "habits of mind, habits of heart, and habits of hand" (Shulman, 2005, p. 59). Together, they provide a framework within which we may examine pedagogy beyond the surface activities observable in the classroom.

Shulman (2005) considers signature pedagogies as "pedagogies of performance". An example of this would be teacher training students who, as part of their training, are required to "publicly" perform their learned skills in ways that mirror the public performance of their future professional skills. Investigating pedagogical practices in education is often challenging because many factors could potentially influence the teaching-learning journey. (McLain, 2021, p.11) argued that these structures are "located" in the curriculum, the teacher and the learning environment. In this article, we place them in a wider context, including teaching methods, and relationships between teacher and student, learning rules, norms and culture.

1.4. What is the Global Science Opera?

The Global Science Opera (hereafter GSO) is a global creative educational initiative in which science and arts are explored simultaneously in a transdisciplinary framework. It is made possible through digital interactions. It is a "network of scientists, art institutions, schools, universities, in all of the inhabited continents" (Global Science Opera, 2016). The GSO website specifies that the GSO vision is to produce annual Global Science Opera productions during which a global community will explore interwoven science, art and technology within a creative and democratic inquiry process. GSO exists at the meeting point of science and art, of students and scientists, of research and practice, and of all human cultures. Song, music, dance, drama, eco-art, animation, puppetry, and other artistic expressions, seamlessly interact with, and become integral parts of, the scientific inquiry in which students engage (Sotiriou et al., 2019).

Annually, students from elementary to university-levels collaborate with teachers, researchers, artists, and scientists to create and perform a performance on the world-wide stage of the internet. Each year a new over-arching scientific topic provides the opera´s inspiration, and each participating school, country works with a sub-topic for their scientific inquiry. During the period 2015–2021, 7 annual productions were implemented: "Sky Light" (2015), "Ghost Particles" (2016), "Moon Village" (2017), "One Ocean" (2018), "Gravity" (2019), "Energize" (2020), and "Thrive" (2021).

GSO transforms students' learning environments for students and connects them to real-world questions. In teaching science, GSO aims for the positive effects the arts have on teaching skills and abilities such as reasoning, relating and problem solving, communicating, cooperation and sharing ideas, as well as students` attitudes towards science (Ben-Horin et al., 2017; Sousa et al., 2016).

GSO's global momentum, and innovative status, encouraged us to consider it a relevant candidate for development as a signature pedagogy.

1.5. The GSO as a transdisciplinary signature pedagogy

Methodological contours. Methodologically, this paper represents a conceptual and interpretive approach aiming to bring order to the GSO initiative by combining two forms of analysis: integrative literature review on the GSO and an interpretation of signature pedagogy in a global, transdisciplinary science-art context. Together, these forms of analysis reconstruct GSO practices as a signature pedagogy. Taking into consideration Shulman's signature pedagogies description mentioned above (p. 4–5), we analysed educational sources of the GSO4SHOOL project (The GSO4SCHOOL Framework and Master Plan, GSO4SHOOL Teachers Guidelines), and various resources available online: (Sotiriou et al., 2019); Global Science Opera, 2016). As supporting material, recoded videos of GSO performances (2015–2020) have also been reviewed.

Our analysis starts with an assumption and disposition that the GSO has legitimacy as any other discipline/phenomenon and a key characteristic (unique and specific features). Before we contemplate its development as a signature pedagogy, we must briefly outline the GSO overall intention and vision.

2. GSO roots

The GSO pedagogy has relied on ***4 underlying theories: Inquiry-based learning (***Ben-Horin, 2014***); Wise Humanizing Creativity (***Chappell et al., 2012***); Design Thinking education (***Sotiriou et al., 2019***), and a STEAM approach in education (***Colucci-Gray et al., 2017). A symbiosis of these demonstrates multiple perspectives to science teaching and learning seeking to develop "creativity, curiosity, critical thinking and collaboration, which lead to experimentation and inquiry" (Robberstad et al., 2019, p. 6). Furthermore, the GSO is a structured and acting teaching form in which students and teachers examine science through three main pillars: learning to know science through an art-based approach, learning to act by developing capacities and skills, and learning habits of collaboration (e.g., building meaningful and multicultural networks and participatory practices).

We recognize two inter-related traits in the GSO structure: a) teaching and learning as a creative process and b) performance as final result.[2] This closely relates to the concept of signature pedagogies, in which students have to learn as well as *demonstrate* their learned skills. Shulman (2005) describes signature pedagogies as "pedagogies of performance" because as part of their training, students must publicly perform their learned skills in ways that mirror the public performance of their potential future professions (e.g., scientists, artists, educators). Both the process and final result have a common aim—to help students acquire, perceive and perform scientific knowledge.[3] This structure allows GSO's participating students, teachers, scientists, and artists to consider scientific phenomena/topics in different perspectives. Thus, the arts open doors to a creative exploration of science.

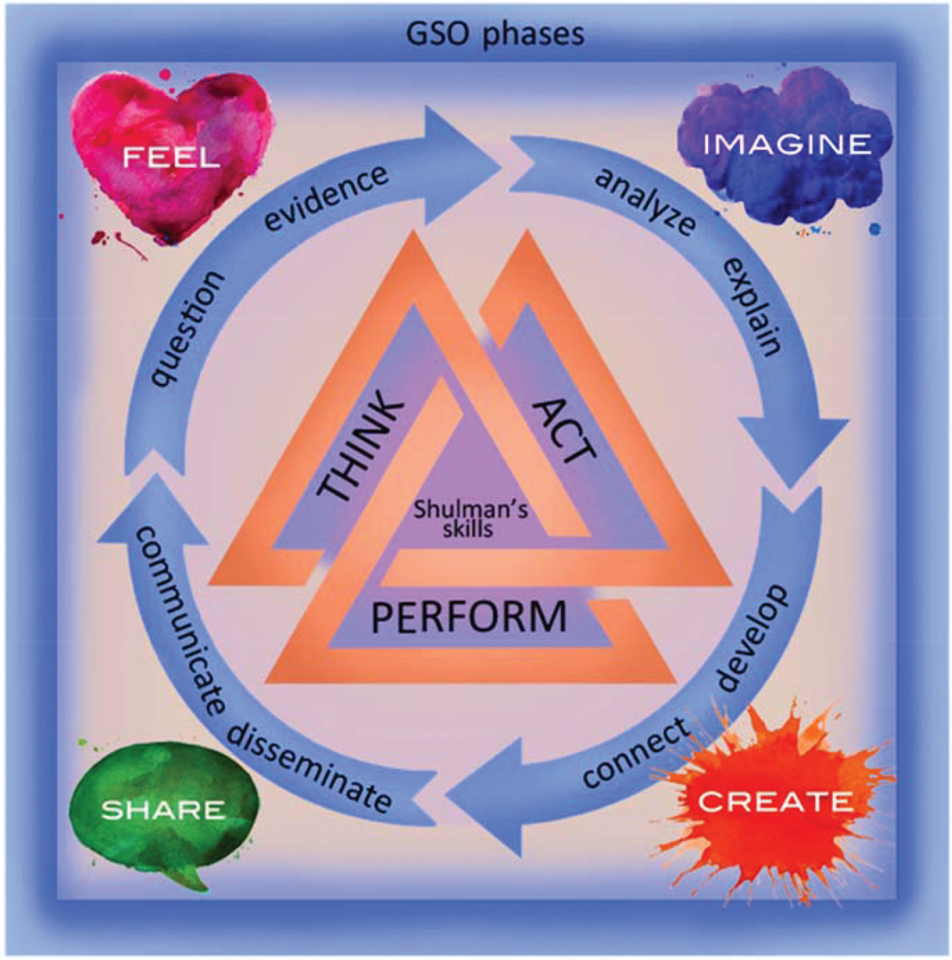
However, from the arts' perspective, the GSO has a different aim. Teaching and learning are focused on the process, while an (artistic) performance may also be characterized as a result aimed towards an audience. This dualistic juncture raises an issue for art educators and artists. For instance, in drama/theatre education, a performance as a final result requires not only content and form, but also an artistic quality, and virtuosity of performance, which evokes feelings from an audience. This challenge has been taken into consideration by the GSO in 2016:

> "While GSO provides many opportunities, it also poses challenges in the areas of implementation, common learning goals across country borders in different continents and different age-groups, common understanding of arts education procedures, the definition of artistic quality in this context, and a disparity regarding technical means" (Ben-Horin et al., 2016, p. 3).

Considering Shulman's (2005) notion of a signature pedagogy, our analysis has brought to attention three distinctive elements of signature pedagogy influencing the GSO. In the GSO4SCHOOL Framework and Master Plan (Sotiriou et al., 2019), teaching and learning processes are based on four phases of feeling (Feel), imagination (Imagine), creation (Create) and sharing (Share). These are based on **Design Thinking** education (see Robberstad et al., 2019) which follow the phases as a practical base "to encourage and describe the creative process and have the ability to lead a process where human beings are seen in a holistic, creative and respectful manner and where any given process is developed in an inclusive way" (Sotiriou et al., 2019, p. 9). GSO thus illustrates a teaching/learning cycle aimed at development of capacities, e.g., to feel, imagine, create and share knowledge, and the development of a value-based attitude. These are indicative of the clear set of instructional events that Shulman described as a signature pedagogy. Figure 1 demonstrates relationships between the GSO Design Thinking phases and students' skills following Shulman's approach.

For the students we introduced in our vignette, and who were working on *Gravity's* main story, the geographical nearness to the historical sites enhanced a feeling of connection to the scientific discovery and made imagining the challenges related to the expeditions which enabled those

Figure 1. Relationships between the design thinking phases in the GSO, and Shulman`s approach to skills.

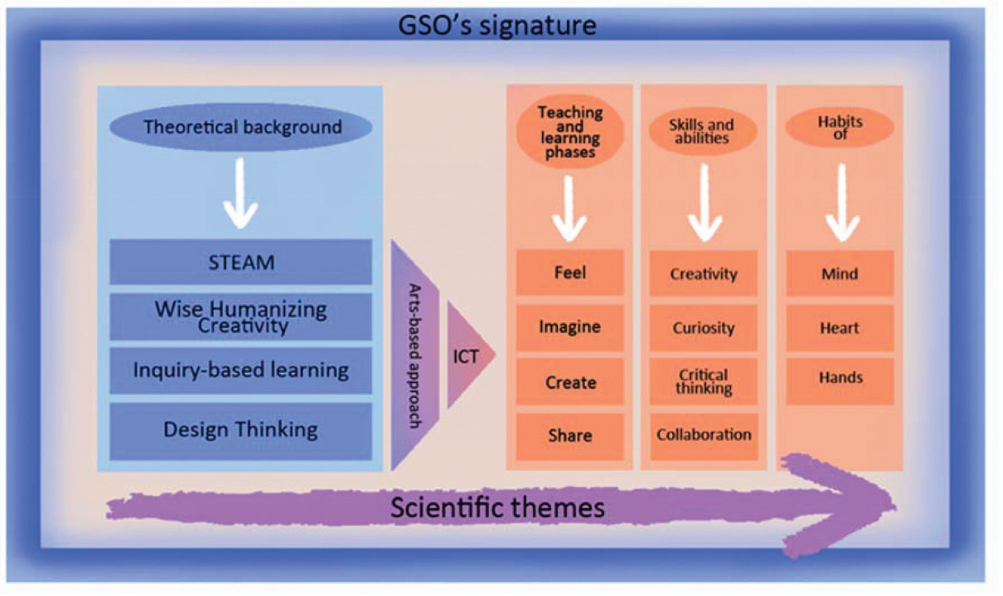


discoveries more tangible. Their creative drama improvisation embodied their new knowledge; refined, rehearsed and shared through celebration as part of a national jubilee.

The first phase, ***Feel (question, evidence),*** includes an investigation conducted in order to collect information about a scientific subject by encouraging students to take and share control in the collective creative process, where they understand the rules and make decisions in consideration of them (Sotiriou et al., 2019). Students identify problems in their close environment, regions, and countries, they observe those problems and seek to engage with those who are affected. They discuss their thoughts in groups, and vote on various ideas (ibid.). This phase addresses real-world challenges and invites students to actively build their own future. It is also the stage where students and teachers together decide on which artistic approach they will choose to explore a global problem as a focus of their exploration.

In the next phase, ***Imagine (analyze, explain),*** students imagine possible solutions to the problem and engage in brain-storming and idea generation. This resonates with Shulman's ***Think and Perform***, in which students engage each other with new ideas through collective, imaginative brainstorming, "with ideas building upon ideas, gradually moving from a quantity of ideas to a quality idea through a collective process. It is also about the willingness to take risks in finding the best solution, immersing themselves into the unpredictable process of creativity" (Sotiriou et al., 2019, p. 16). Moreover, students analyse and categorize the collected data, and they make

Figure 2. GSO as signature pedagogy.



a first attempt to imagine the scenario on which their performance will be based. An essential role in this phase is played by students' improvisation as they attempt to set up a basic skeleton of their performance in a spontaneous way.

The ***Create*** phase ***(connect, develop)*** resonates with Shulman's ***Perform and Act***[4] in which ideas and imagination come into form, the students make their ideas concrete and create express those ideas. In this phase, students develop ideas into action, after having planned in detail how they will achieve their goals and collect. This phase is characterized by students finding their own connections between scientific knowledge with various forms of art (Sotiriou et al., 2019).

In the **Share**-phase, resonating with Shulman's Act and Perform skills (Figure 1), the students distil their knowledge, summarizing their newly acquired skills. The main recipients of this message are the students themselves. The students have created a science-infused story which sprung from their curiosity, nurtured through their creativity, answering their engagement, artistically expressing their educational experience, developing communication skills along the way. The final (opera) product is an integral part of the process, and an integrated part of the learning-situation, also including an external audience. "And even if the learning process is mainly for the participating students, (...) it doesn´t hurt if the audience learns something new too! (...) feedback from the audience can be beneficial as advice for possible later productions" (Sotiriou et al., 2019, p. 16).

Working through the four blended theories and four learning and teaching phases (Feel, Imagine, Create and Share) students explore a scientific phenomenon through and with the arts. In Figure 2, the unique and distinct nature of the proposed signature pedagogy, argued as being suitable for the GSO context, is illustrated.

Taken together, this structure identifies the GSO as a signature pedagogy with a transdisciplinary character, and which can also be viewed as a creative education initiative combining the elements of art that empower students to critically examine their beliefs, values, and knowledge toward collaboration on global science issues.

3. Unique structures of the GSO: surface, deep and implicit

We have drawn on signature pedagogies (Shulman, 2005), identifying a characteristic of GSO that renders it unique. GSO pedagogy is not merely teaching methods, curriculum or environment: it is the unique combinations of their usage in ways that are distinctive to GSO which qualify it as a signature pedagogy. Shulman's three structures (Surface, Deep and Implicit) provide context within which to argue for the uniqueness of GSO's signature. The **surface** structure involves operational elements of how learning and teaching processes are organized in GSO. The **deep** structure involves integration of the arts in a transdisciplinary science education context (Table 1). The **implicit** structure highlights moral aspects of teaching and learning including beliefs, value-based attitudes toward different nationalities, cultures and democracy.

We acknowledge that in GSO, the three structures currently are at different levels of readiness with regard to how developed they are: The surface structure is well-developed. With regard to the deep structure, we acknowledge certain weaknesses and limitations, and especially when we analyse a set of assumptions about how best to impart scientific knowledge in the context of a transdisciplinary approach. The implicit structure is the best developed in GSO and has the greatest impact tackling the global dimension of a scientific issue that also relates to human beliefs, positions, values and attitudes.

4. Surface structure

We have chosen to demonstrate operational acts of teaching in the following areas:

Selection of topics for annual GSO productions was, during the initiative's first years, serendipitous: topics were proposed by central members in the network. In recent years, a more systematic approach has been implemented whereby GSO educators vote on ideas presented by the network in the context of professional development courses.

The **creation of opera scenes** occurs by means of a process in which a school receives a scientific idea for their scene, following which they write the libretto and compose music for it, and perform that scene during the opera (Ben-Horin et al., 2016, p. 10).

The **science curriculum** in GSO consists of inquiry-based study of data, ideas, scientific phenomena and science history, all of which are integrated into art activities. GSO's organizers aim to integrate themes relevant to the global community.

Students partake in **dissemination activities** as they perform and promote their global performance, thus contributing to interaction between their school and its surrounding society (ibid.).

Relating this to the example presented in our vignette: Pre-pandemic, four student-groups in Sao Tome & Principe (STP) and Brazil collaborated simultaneously physically with their classmates and digitally across the ocean through Skype and Google-docs. This way they could see each other, talk together and immediately see each others' written ideas.

5. Deep structure

We have chosen to demonstrate assumptions about how best to impart knowledge and know-how in the following areas:

An **arts-based approach** transforms the environment for teaching and learning, yet we acknowledge that various approaches to this approach may co-exist.[5]

GSO constitutes a dialogical space (Chappell et al., 2012) with the aim of **engaging** students in science and art lessons, and a better insight into the nature of scientific inquiry and the ways in which scientists work.

GSO operates by means of physical and web-based **communities of practice** thus constituting a network on the national and international levels (Ben-Horin et al., 2016).

GSO makes the assumption that participating teachers are willing and able to innovate as part of a larger network.

Table 1.. The key characteristics of the GSO according to Shulman`s three structures

Structures	Surface "…concrete, operational acts of teaching and learning, of showing and demonstrating, of questioning and answering, of interacting and withholding, of approaching and withdrawing…"	Deep "…a set of assumptions about how best to impart a certain body of knowledge and know-how…"	Implicit "…a moral dimension that comprises a set of beliefs about professional attitudes, values, and dispositions…"
Curriculum	A creative and democratic inquiry process based on 4 stages: Feel, Image, Create and Share actions where students analyse scientific phenomena.	Transformation of science curriculum. Integration of various arts elements in teaching and learning science through a transdisciplinary approach.	De-isolation of science. De-centred creative approach and social interactions.
Teacher	Didactic guidelines for teachers (the GSO Guidelines for teachers, GSO4SCHOOL framework, etc.)	Horizontal, vertical and diagonal collaboration between teachers, scientists and artists. Integration by teachers based on showing professional commitment and passion.	To see a power of science in the global light (ecological sustainability, democracy, intercultural values etc.). A sensitivity toward student educational, cultural and ethical needs.
Student	Students gain knowledge using experiential forms of learning. They use art activities seeking to analyse scientific phenomena.	To facilitate inclusion of all students regardless of circumstance. GSO provides learning opportunities in which students from around the globe may cross-inspire and learn from and with each other. Students learn about science through creativity and art.	To being a crowd-sourced collaborative creativity environment, it provides social and emotional settings during which students of various cultures, traditions, ages and religions explore together.
Environment	A global educational environment given by art activities. Integration and interaction of IT technologies.	A transdisciplinary educational environment for GSO implies a blurring of the boundaries between the various disciplines.	Collaborative and multicultural environment, well-being of the local, national, and global community.

Relating this to the example presented in our vignette: The STP and Brazilian students spoke Portuguese, and could easily engage in trans-Atlantic communication. Their common creative effort evolved into new appreciation of each others' historic and contemporary contributions. New friendships were formed across borders.

The STP and Brazilian students needed a deeper understanding of the scientific matter in order to communicate it in a good way to others. A deeper understanding of gravity was achieved through an array of workshops, fieldtrips, exercises and experiments, before creating the script and performing the narration. The focus was less on them, more on communicating the science in an engaging manner.

6. Implicit structure
We have chosen to demonstrate moral dimensions that comprise a set of beliefs about attitudes, values and dispositions in the following areas:

GSO focuses on interaction between students and the **social and cultural contexts** in which they live. This approach supports empathy in students, as they engage with their communities as active participants.

GSO provides students with the confidence to be **innovative and creative** regarding how they approach solutions for challenging problems (Sotiriou et al., 2019).

The GSO enables a place at the intersection of education, technology, science, art and society in which all stakeholders may connect and explore ideas that may be realized with a **common purpose**: the well-being of the local, national, and global community, and a more just and sustainable world.

The GSO practice emerges out of a balance of **respect, autonomy, collaboration, play and design**.

(Chappell, 2018) contemplates the ways in which a global educational environment may contribute to inviting **pedagogical humility** on the part of human participants in the educational context. Chappell et al, (2019). encourages educators to consider how we might step outside of ourselves. We take from this, that for the GSO a creative transdisciplinary initiative means that we would benefit from "de-centring" the site of creativity from being limited to that which is human. We understand GSO's focusing on themes such as the ocean, gravity, energy and ecosystem restoration represents such a "de-centring". Indeed, the process of decentration marks a transition from an egocentric view of the world to one in which the subject becomes capable, through social interaction, of understanding other perspectives (Piaget, 2007).

The GSO website exemplifies these issues as follows in the announcement of the GSO "Thrive" 2021: *"Global Science Opera is about much more than an opera (…) It is about changing minds, producing creative thinkers and imaginative problem solvers, widening expectations on what is possible, raising awareness of sustainability issues, showing what can be achieved through the powers of technology and working together, and reaching out across the world affecting the schools, communities, parents and families of the children, students and teachers involved"* (by J. I. Robberstad).

7. GSO is a transdisciplinary education initiative
In the 21st century, students must relate to scientific and technological breakthroughs, and face global problems and possibilities that can only be addressed in a multivariate context. A transdisciplinary approach to school education enables engagement with different ways of knowing the world, generating new knowledge and experience: in a transdisciplinary context, disciplines reside as separate yet connected and permeable entities (Marshall, 2014, p. 107).

Transdisciplinarity provides a broader framework for education as it is well suited to create interactions between science and art, and demonstrate how these disciplines can be parts of a wholistic system. GSO aims to achieve this. "The GSO is a global, trans-disciplinary creative education initiative made possible through digital interactions (Ben-Horin et al., 2016, p.3).

Complexity is an important consideration. By acknowledging the complexity of our world, with hyperobjects like the new climate reality (Morton, 2013), we stand stronger in the face of global challenges. Reducing disciplinary boundaries, and blurring the lines between subject areas, increases the surface-area of perception in the holistic human, and with it, a deeper understanding needed to collectively tackle these multi-dimensional challenges. In the GSO, a transdisciplinary methodology conveys science as a common, global contemporary heritage, creatively explored though feelings, imagination, creativity and sharing. This is an opportunity to shape a new paradigm of teaching and learning built on a more dynamic, creative, organic, and realistic vision of how the world works.

8. Final remarks

Using Shulman's theory as a basis for analysing GSO as a signature pedagogy, we hope to have provided a coherent picture of the GSO, which relies on arts integration in science with the aim of opening new spaces of teaching and learning in a multicultural environment.

We realise that our approach and analysis have limitations because any theoretical conception of something so complex as transdisciplinary learning and teaching processes must be modified and interpreted in terms of the current situation and future perspectives. In realizing STEAM ideas in science-art education, the GSO provides a transdisciplinary context for the subjects of different disciplines in science and art to converse. As has been noted, GSO combines teaching and learning processes oriented towards learners themselves, as well as the final result—a performance, which is addressed to audiences. We have argued that learning how to communicate science through art is an equally important skill as learning how to learn science through art (Akhutina, 2003).

At the same time as we observe several strengths and potentials GSO as a signature pedagogy, it is important to acknowledge that the current GSO methodology may contain weaknesses as well. Different countries have different approaches to and accentuations of elements of the science, art and technology curricula. A common scientific topic may, then, require some GSO schools to invest time in studying issues which do not directly relate to their stated learning objectives. In addition, while the fact that GSO is open to pupils of all ages is inclusive and potentially enabling of interesting synergies between different age groups, the needs of e.g. first graders (6–7 years of age) are vastly different than those of their high-school peers (16–18 years of age). Balancing these in a way which is meaningful for all groups requires much attention, and perhaps even methodological compromises.

We also think that the current four described phases of GSO ***(Feel, Imagine Create, Share***) inspired by Design Thinking theory applied in a transdisciplinary context, may benefit from a revision. As an example, the phase conceived of as ***Feel*** is very important for GSO from an arts perspective. However, if ***Feel*** is understood as a rational human capacity as well as an affective one (e.g. Best, 2012) it makes sense in a pedagogy where art and science come together to collaborate with the aim not only of the "knowing and doing" elements, but also of the "feeling and perceiving".

Furthermore, the GSO performances (Global Science Opera, 2016) exhibit potential for further artistic development. Indeed, there is a need for a deeper discussion about the aesthetic and artistic quality of the art created by GSO students worldwide. One way of understanding an aesthetic quality is as an energy the artist wants the audience to feel, and which allows the artist to convey a message in order to make feelings perceived and felt (Straksiene et al., 2009).

Straksiene's (ibid) perspective may, then, based on the arguments in this article, guide the GSO's aesthetic and artistic development in years to come.

We have argued that Global Science Opera's signature illustrates how global issues may be integrated into the science curriculum through arts activities, by employing a transdisciplinary approach. It provides policy-makers and educators with new knowledge of pedagogical processes and transdisciplinary practices. Modern-day events which impact the health of our planet and humanity's chances for survival (e.g., climate change, pollution, water contamination, ozone depletion, loss of bio-diversity and ocean acidification) make it crucial that students and teachers are aware of the complex nature of potentially achieving long-term sustainability (Robberstad et al., 2019). Indeed, GSO's signature supports the 21st century skills of creativity, innovation, and collaboration. Furthermore, these capacities are directed to the "Transformative Competencies" that together address a growing need for young people to be innovative, responsible and aware: creating new value, reconciling tensions and dilemmas, and taking responsibility (OECD, 2018, p. 5).

It is our hope that this work will provoke further discussion, which we see as necessary in order to transform the educational reality on our planet. In the future, we aim to further extend GSO's signature to embrace a Post-humanizing creativity (Chappell, 2018). Post-humanizing creativity (ibid) questions the anthropocentric worldview, challenging us to see a more organic vision of how the world works: while the international human-to-human collaboration characteristic of GSO is peace-work in practice, the methodologically innate trans-disciplinary approach to arts integration in science should, in the future, be expanded to human to non-human intra-action as concept and practice for a more ecologically sustainable future.

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Notes
1. Information in vignette has been approved by the Norwegian Centre for Research Data, project number 60,740.
2. Typically, the teaching and learning process of the GSO lasts approximately 1 year. The performance itself lasts for 1–2 hours.
3. We need to add some words here about the tension between a transdisciplinary approach on one hand and the fact that we continuously communicate that we want to support science teaching.
4. We understand Shulman's skills as: Act is the intent, Perform is the implementation or communication.
5. Questions revolve around whether art is a product or process, what art education is and is not be in science education, and criteria for assessment, among others (Global Science Opera, 2016).

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