Chapter 31
STEAM Education—A Transdisciplinary Teaching and Learning Approach

Jack Holbrook, Miia Rannikmäe, and Regina Soobard

Chapter Overview

The purpose of this chapter is to recognise the need for a wider view of the science education domain, above and beyond the traditional biology, chemistry and physics, thus seeking the need to encompass technology, engineering, mathematics and also other societal important areas such as art (in its multiple conceptions). This view is seen as STEAM-ED. The approach to STEAM-ED, however, rejects a disciplinary focus and seeks to promote transdisciplinarity, emphasising transdisciplinary skills within a sustainable, world view, based on inquiry learning and using an approach based on social constructivist theory within an 'education through science' frame.

Introduction

Science education has undergone many changes over the last century in response to differing perceptions of the role of education and its purpose in the school setting. While 'science for scientists' can be taken to represent an intellectual, factual and conceptual approach, perhaps heavily embedded in a historical development, other approaches such as science-technology-society (STS) can be seen as more functional and bringing science learning closer to the realities of everyday life (Aikenhead, 1994). According to Holbrook and Rannikmäe (2009), scientific literacy (SL), or the

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more society-related, scientific and technological literacy (STL) seek to bridge this divide, seeing both an academic scientific conceptual challenge and a 'science for all' vision. These literacies are also geared to include the development of personal and social skills for responsible citizenship and the acquisition of employability skills (Holbrook & Rannikmäe, 2014). However, whether science education is a prerequisite for emulating a scientist, or for functioning in everyday life, there is always the concern that the science learning is confined to solely scientific ideas and lacks coherence to technology, both as useful science applications in society and as tools to aid science learning. In regard to engineering, science underpins the design, creation and improvement of constructions or products, within the artificially created world as we know it, and towards underpinning all this through mathematical applications. These concerns can be envisaged within or across local, national and global environments, and extend to socio-scientific issues involving creative learning associated with social studies, perhaps focussing on sustainability, artistic endeavours, ethical aspects and other social interactions.

The approach to science education has moved away from a behaviourist learning base. This view assumes a learner is essentially passive, responding to environmental stimuli and behaviour is shaped through positive or negative reinforcement for which the goal is a permanent change of behaviour often translated into memory recall, or comprehension of isolated scientific concepts. Much emphasis is being placed on promoting an inquiry-based or problem-solving learning frame, and in seeking ways to make the learning within science education more intrinsically motivational for students. Strongly encouraged in this area are student-centred practices, based on self-determination theory (Ryan & Deci, 2000) and differential learning within the so-called zone of proximal development (see Chap. 19). Yet there is still a preponderance of a subject specific, content focus, often in individual sub-disciplines within the science field, yet desirably building on a 'simple to complex' vision of learning within the subject itself, but only allowing societal links as a distant after-thought.

This chapter is seeking to re-examine the role of science education in today's changing world. It is based on the realisation that science education is far different in reality from science itself. Science, as a philosophical endeavour, has an ancient history, heavily based on observation and explanations, and formulating theories and laws. However, in the twentieth and twenty-firstcenturies, numerous technologies have emerged which are invading our lives and, through acting as aids within society, have promoted the frontiers of changing lifestyles of people today. While technology may be difficult to define, and artistic design may enable some technologies to become more attractive and popular than others, the interrelationship between science and technology is ever-present. This is even more so when reflecting on the role of engineering and designing within today's created world. There is little doubt that the industrial revolution, arguably the beginning of modern technology, started by the ability to make available cheap and abundant energy (in this case steam power), stimulated further scientific progress. As a result, the developments in technology played a strong role in the new discoveries and developments in science, which in turn, furthered the developments in technology, of which engineering, as the design creation and improvement of technology, played a major role.

But alas, technology, and hence the interrelated science, can be both good and bad. Whether this is related to facilitating today's lifestyle (e.g. modern means of transport, supporting the increasing longevity of human life, the development of the digital world and artificial intelligence), or raising concerns about global warming, environmental degradation, sustainable ways of life, or the engineering of new technologies, all having a foundation in scientific advancements and yet have led to major social dilemmas in today's world. Furthermore, while design can take on an aesthetic dimension, it can lead to ethical and moral dimensions, all indicating the interrelationship of scientific endeavours with the social world. In short, in today's world, the science education dimension, encompassing learning associated with technological/engineering developments, is intertwined with the human or social dimension, especially so when seeking a sustainable world. There is a growing recognition that the learning associated with decision making within socio-scientific issues cannot be ignored, both in societal debates and also in the school science curriculum.

In recognition of the changing world, science education, or the education processes related to an understanding of the natural and artificial world, are, by necessity, also changing. Science education is widening to take note of technological links, societal involvements, creative problem-solving abilities and, inevitably, related to such developments, to make informed decisions, related to both technological choice and socio-scientific reasoning. Science education, even at the school level, can no longer function as isolated training in the promotion of higher level cognitive skills, or even that accompanied by creative, practical endeavours associated with cognitively driven psychomotor skills. Science education cannot ignore its mathematical base, and its interrelationship with the natural and artificial world. Science education has a role to play in preparing today's youth for a future, changing society, preparing students to relate to changing career opportunities and the need to recognise conflicting societal values, whether these are linked to religious intolerance, ways of life, or individuals' freedoms and limitations.

Enhancing STL is a multi-faceted vision and needs to relate to education, itself a moving frontier. With a multi-faceted vision of the role of education, it is inevitable that the older need to keep up with coverage of the ever-expanding scientific knowledge is very much diminished. The needs of society, whether associated with issues related to the local, national or global environment, or the understanding of interactions between the natural and technological world, suggest a demand for strong socio-scientific interlinking. With this, there is a growing need for bringing together scientific ideas, technological endeavours and engineering practices linked to social priority choices. The latter encompasses social, even artistic values, leading to a suggested intermix of scientific endeavours, through the enhancement of transdisciplinary skills, with wider areas of learning, seeing the whole (the overall education gains) as greater than the component parts (the education within subject sub-divisions).

Thus, this chapter proposes that science education is in need of moving from science disciplinary education (SE), from a science and technology education (STE), and even from a science-technology-society education (STSE), to a new vision of scientific and technological literacy (Holbrook & Rannikmäe, 2009). A transdisciplinary scientific and technological literacy (STL) is encapsulated in terms, such as STEM (science, technology, engineering, mathematics), or even more, in recognition of the social or artistic direction, STEAM (science, technology, engineering, art, mathematics), not forgetting that STEAM in relation to education, especially within a transdisciplinary view, can lead to the realisation of STEAM-ED as the new STL goal.

The Theoretical and Philosophical Underpinning of STEAM-ED

The approach to learning within science education is grounded on constructivist theory (see Chaps. 16–26, especially Chap. 18). In interrelating science conceptual learning with socio-scientific relevance, social constructivism is very much favoured. Linked to this is the growing recognition of the importance of the context in which the relevance of the learning for the learner is enhanced.

The recognition of the education emphasis within a vision for science education can be captured through the expression 'Education through Science (EtS)' (Holbrook & Rannikmäe, 2007). The term 'Education through Science' can thus be proposed as a philosophy. This recognises that the learning approach to education relates to the issues and concerns of society (both present and futuristic), although just because something is related to everyday life does not automatically mean it is seen as relevant to students. The relevancy is likely to be linked to the immediate concern or issue of the society, expressed in the media and impinging on the students' daily life (from a local, national or global perspective). The emphasis on relevancy and issues and concerns is seen to be important. However 'education through science' portrays science education learning as appreciating the nature of science, developing within student intellectual development as well as positive attitudes and aptitudes, and acquiring skills associated with society development especially those linked to interpersonal relationships and in making informed socio-scientific decisions within society (Holbrook & Rannikmäe, 2007).

Yet as a philosophy, 'education through science' goes further. It recognises the need to undertake academic challenges, preparation for the world of work and the need to promote responsible citizenship. It seeks to encompass key learning competences for education, and thus provides a focus for the needs of students in learning 'how to learn' through the gaining of science and technology/engineering competences (accompanied by mathematical competences), interrelated with the importance of promoting social, cultural, entrepreneurial and digital competences enhancing personal and social attribute development and the need to further promote communication abilities in verbal, written, symbolic, graphic as well as digital aspects. In this, it contrasts with the more standard view of science education, with its focus on lessons labelled science, or a sub-division and organised by subject content.

Formulating a STEAM-ED Approach

In a quest to conceptualise STEAM-ED the following questions can be put forward:

(1) Is STEAM a more meaningful term to represent science education in a wide transdisciplinary sense, or does it need to be seen as a movement to reflect on a multidisciplinary vision of science education, merely seeking to replace STL as the philosophical pinnacle?
(2) Can STEAM-ED be seen as a more meaningful vision at the operational, or curriculum level to promote a skills enhanced, science education focus reflecting a new way of thinking about inquiry that includes a wide range of societal perspectives, or for considering, designing and implementing tangible solutions to "real world" problems?

Refuting a Disciplinary Approach in Education

Mahan (1970) criticised both the compartmentalisation of the traditional disciplines and ideals of detachment and aloofness associated with any disciplinary inquiry. The disciplines, as both intellectual and social constructs, are nothing more than organisational pillars within a system. Disciplinarity, which may be defined as the compartmentalisation of learning into system-defined units, can be perceived as essential for an understanding of an organisation of particular directions of knowledge. However, the knowledge specified in a discipline, thus defining the discipline, only relates to a small part of a larger picture. This leads to the need for a matrix of disciplines with specific methodologies, paradigms and inherited problem areas. Disciplinary thinking is in danger of becoming all-pervasive when one starts viewing and speaking about everyday matters in terms of specific disciplinary concepts and priorities.

Examining Multidisciplinarity, Interdisciplinarity, Transdisciplinarity

To overcome the limits of a given discipline, multiple disciplines can be grouped together, each giving separate isolated inputs, but still giving rise to the danger of omitting a valued discipline to tackle problems associated with a changing world, whether this is in connection with responsible citizenship, employability preparation, or conceptualising advancements. A Multidisciplinary approach involves the collecting of inputs from different disciplines putting them together without synthesis. Interdisciplinarity finds favour in grouping disciplines together leading to collaboration between researchers from different disciplines aimed at a synthesis and

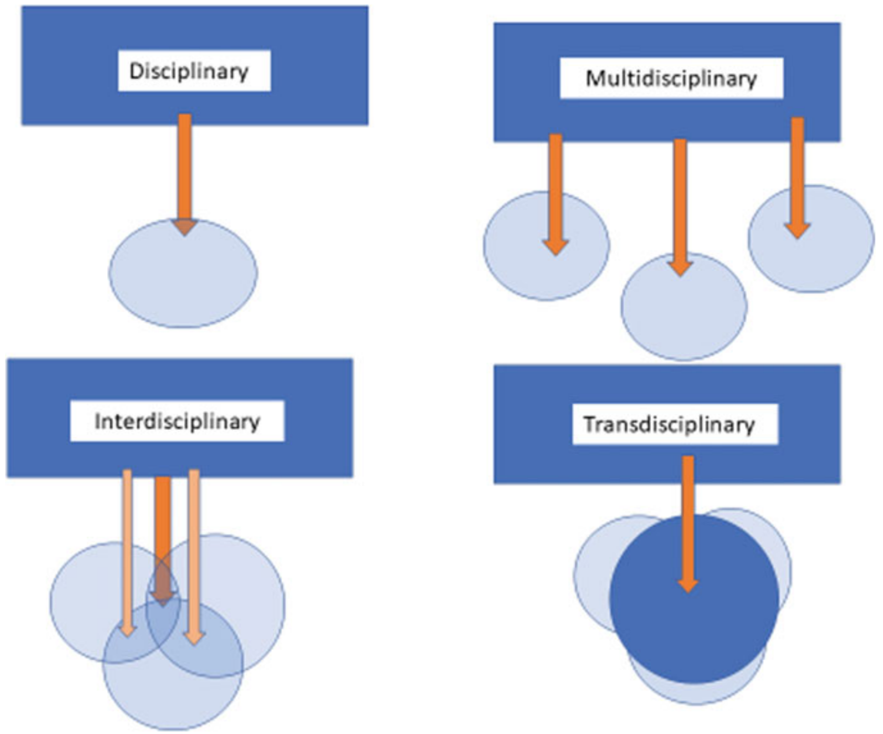

Fig. 31.1 Comparing the four different approaches

integration of knowledge, but the approach is still discipline-led and each discipline employs skills and directions suited to that discipline.

While the distinction between transdisciplinarity, multidisciplinarity and interdisciplinarity need not be sharp or absolute, transdisciplinarity generally rejects the separation and distribution of topics and scholarly approaches into disciplinary compartments (Choi & Pak, 2006).

Below is an illustration of the four different approaches (Fig. 31.1).

A Transdisciplinary Focus for STEAM Education

Transdisciplinarity is a new way of thinking about, and engaging in, inquiry (Montuori, 2008). It goes *beyond* disciplines and identifies with a new knowledge about *what is between, across, and beyond disciplines* (thus the term *trans*)" (McGregor, 2015) and includes approaches from ethical, metaphysical, and even mystical perspectives aiming at designing and implementing tangible solutions to "real world" problems. On the one hand, it can emphasise a concept of the human life world and lived meanings, while on the other, it can emphasise skills to tackle the interface between science, society, and technology in the contemporary world (ibid).

Transdisciplinarity seeks the framing of a topic/big idea as an overarching theme for the inquiry process. It moves instruction beyond just the blending of disciplines and links concepts and skills through a real-world context. Within science education, it aims at creating an engaged socially responsible science. For example, the notion of sustainability has evolved from a concept to a movement involving not only science, government, and industry, but citizen participation, including input from religious leaders, consumer awareness, boycotts and protests, and much more (Cardonna, 2014). Furthermore, with concerns voiced about a possibly dying planet, the need to prevent catastrophe lends a sense of transdisciplinary urgency to this work, with a necessity to not only to raise awareness, but provoke an informed change of behaviour. Evans (2015) has written of a sustainability crisis and thinks educators need to situate their discussions of sustainability in terms that are not only scientific, but ethical, involving "intergenerational fairness extending over long timeframes and on the health and integrity of human societies and the natural world." Sustainability can this be considered as an example of the expected direction of science education learning within transdisciplinary STEAM education?

Transdisciplinary education re-values the role of intuition, imagination and sensibility in the transmission of knowledge. Transdisciplinarity is sometimes described, at least in part, as a response to the increased complexity of contemporary problems in science and technology. Indeed, complexity itself could be a problem area for transdisciplinary studies. Complexity is not exactly synonymous with complicatedness, since a complicated system may be understandable in terms of its components, while in a complex system the individual components interact with each other and with their environment in such a way that the system as a whole cannot be explained in terms of its parts.

What sets transdisciplinarity apart from other approaches, and what assures its role in twenty-first-century education, is its acceptance of, and its focus on, the inherent complexity of reality. This is realised when one examines a problem, or phenomenon from *multiple angles* and *dimensions,* with a view towards discovering hidden connections between different disciplines (Madni, 2007). It is in using this multidimensional complexity to analyse problems and communicate and teach lessons about them that the novel contribution of transdisciplinarity lies (Bernstein, 2015).

Transdisciplinarity does not necessarily need to be seen as applied or practical. Macdonald (2000) insists that transdisciplinarity is as much about the liberal arts, and about cultural symbolisms, as it is about the so-called social and natural sciences, or professions like medicine, engineering, or law. Nevertheless, transdisciplinarity can be viewed as utilising skills for knowledge production, involving knowledge developed for a particular application and involving the work of experts drawn from academia, government, and industry.

Characteristics of Transdisciplinary Inquiry

According to Bernstein (2015), transdisciplinary inquiry-based focus is expected to involve:

(a) transcending disciplinary boundaries in an attempt to bring continuity to inquiry and knowledge;
(b) attention to comprehensiveness;
(c) context and frame of reference of inquiry and knowledge;
(d) interpenetration of boundaries between concepts and disciplines;
(e) exposing disciplinary boundaries to facilitate understanding of implicit assumptions;
(f) processes of inquiry and resulting knowledge;
(g) humanistic reverence for life and human dignity; and
(h) a desire to actively apply knowledge for the betterment of individuals and society.

A further property is *emergence*. Emergence, explained by Holland (2014) through the wetness of water, is seen as a characteristic of 'wetness' which cannot reasonably be assigned to individual molecules. Thus, the 'wetness' of water is not obtained by summing up the wetness of the constituent H_2O molecules—rather 'wetness' emerges from the interactions between the molecules.

A further key characteristic of transdisciplinarity is the tendency to think laterally, imaginatively and creatively, not only about solutions to problems, but on the combination of factors that need to be considered. Thus, inputs from the arts and humanities can transform research and education in sustainability, or other topics that are traditionally viewed as scientific, into an entirely new kind of product (Clark & Button, 2011). This leads to seeing desirable attributes to be developed, abilities to think in a complex, interlinked manner, and engaging in new modes of thinking and taking action.

According to Yakman (2008), STEAM education is an example showing how the boundaries between subjects can be removed and more integrated approaches to science teaching can take place in school settings. Integrating Arts into STEM, the fields of science, technology, engineering and mathematics education, supports students' cognitive, emotional and psychomotor growth, critical thinking, problem-solving skills, creativity and self-expression (Ge, Ifenthaler, & Spector, 2015). Art is an essential component, adding the construction of meaning, expressing observations and creativity (Ge et al., 2015), and working with other to develop transferable skills and abilities to deal with complex problems innovatively and creatively.

STEAM education seeks to relate to careers in truly "helping" professions that build communities and transform nations. These professionals are in charge of solving the complex problems of today's world and its future. They are working to find solutions for global warming, cancer, third world hunger, disappearing habitats, and an interdependent world economy. Yesterday's stereotype of the 'geek' in a lab coat is not representative of today's STL vision, where economists work with researchers on technical transfer and engineers build the state-of-the-art equipment for businesses working with cutting-edge technologies.

The STEAM-ED Emphasis on Skills

Much attention in science education has focused on the development of twenty-first century skills (see Chap. 32). Although these can be defined, grouped and determined differently in specific settings, an overview can be identified as

- Critical thinking, problem-solving, reasoning, analysis, interpretation, synthesising information;
- Research skills and practices, interrogative questioning;
- Creativity, artistry, curiosity, imagination, innovation, personal expression;
- Perseverance, self-direction, planning, self-discipline, adaptability, initiative;
- Oral and written communication, public speaking and presenting, listening;
- Leadership, teamwork, collaboration, cooperation, facility in using virtual workspaces;
- Information and communication technology (ICT) literacy, media and internet literacy, data interpretation and analysis, computer programming;
- Civic, ethical, and social-justice literacy;
- Economic and financial literacy, entrepreneurialism;
- Global awareness, multicultural literacy, humanitarianism;
- Scientific literacy and reasoning, scientific methods;
- Environmental and conservation literacy, ecosystems understanding; and
- Health and wellness literacy, including nutrition, diet, exercise, and public health and safety.

These skills, grouped into five main areas and more specifically categorised can be considered transdisciplinary skills, as illustrated in Fig. 31.2.

Examples of STEAM education in a Transdisciplinary frame

Example 31.1 *Water* (Bernstein, 2015)

A subject such as water falls between the various disciplines and is easily ignored or taken for granted by scholars since it seems on the surface to be neutral. A feature of the landscape, water is something used by animals and plants or that gets combined with other substances, something that makes everything else work, but that seems rather lacking in character in its own right, even though life itself could not exist without it. It has a chemical basis and can be studied from a chemical or physical perspective (hydraulics and hydrology); it is also important in technology, engineering, manufacturing, and equally important, the culinary arts, since there could be no food or drink without water. It is a component of nutrition, digestion, physiology and health; there are sanitation and purity considerations in using water and having it in our environment. There are cultural and religious aspects of water and it is a theme in all the arts. Geographers, geologists, economists and agricultural scientists could

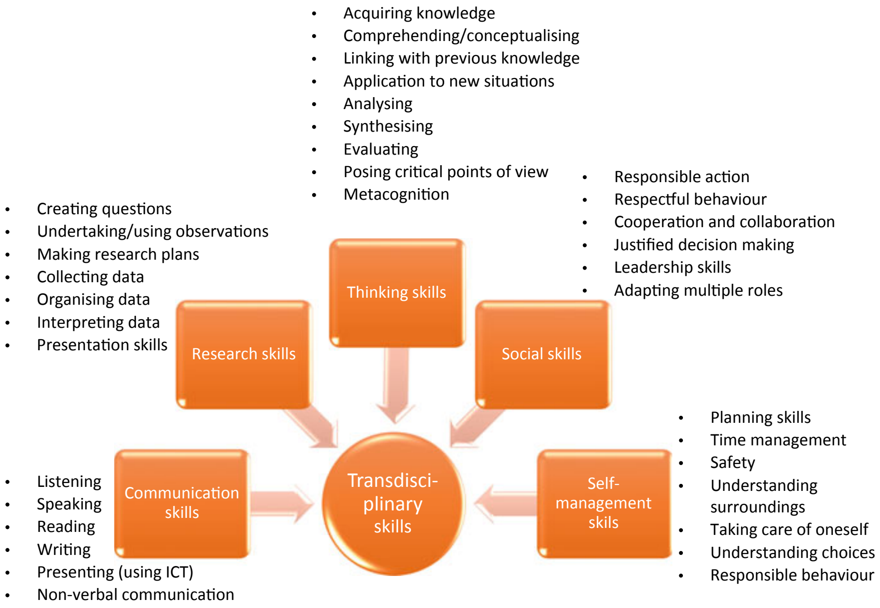

Fig. 31.2 Transdisciplinary skills

study water as a resource. Obviously, the sustainability of water as a resource is an issue, as in the problem of waste caused by packaging in disposable water bottles. There are even political aspects to an important resource such as water, shortages of which can lead to famine, war, revolution, or other vast socio-political changes. One could continue *ad infinitum* about the innumerable facets of water that need to be studied. Questions about water bring together the social sciences, humanities, physical sciences, biological sciences and practical arts and sciences in ways that can be enlightening for educational purposes on the interaction between disciplines.

Example 31.2 Water *related to a STEAM-ED focus*

In this example, A STEAM education approach is used in developing an optional course for 10–12 grade students in Estonia. The whole course includes eight modules, each starting with a motivational scenario introducing a relevant, science-related problem in a society setting to students. Following this comes a science learning component (using an inquiry approach to conceptualise new science content knowledge) and this is followed-up by students relating their new knowledge (science, mathematics) and skills (scientific, engineering, technology, etc.) to interact further with the initial issue faced in the scenario and seek to make a justified decision, based on evidence available for them. In this part, students also need to demonstrate creativity, design skills (for example, product design) and self-expression (oral or written communication, for example). Therefore, the three stages brings together a multitude of disciplines from SSI to STEM to creativity design and self-expression, which now can be referred as STEAM education. This skill-driven approach focuses heavily on social and self-management skills, while the frame is driven by research skills involving all relevant components of STEAM that lead to focused and justified decision making across a transdisciplinary spectrum.

Conclusion

STEAM-ED is seen as a way of interrelating science education to the relevance and issues of society at a local, national or global level, or even beyond into the universe, or even the world of fantasy. Such interrelatedness is seen as problematic, if viewed at a single discipline level and seen as the compartmentalisation of learning into system-defined units perceived as essential for an understanding of the organisation of knowledge. Transdisciplinarity, on the other hand, promotes across curriculum skills and leads to a new way of thinking about knowledge and inquiry. It identifies with a new knowledge about *what is between, across, and even beyond disciplines.*

By and large, the term STEAM or STEAM-ED merely replaces the term STL in its philosophical and societal-related considerations, both seeing science education as wider than the science disciplines and seeing education relating to societal values, employability needs and sustainability at an international level. It is proposed that STEAM-ED can seek more acceptability if it portrays science education in a wide transdisciplinary sense, going beyond, but interconnecting, the individual disciplines. Even more the term STEAM-ED, recognising the education thrust, can be favourably considered in reflecting on new ways of thinking about inquiry that include a wide range of societal perspectives, and for considering, designing and implementing tangible solutions to "real world" problems.

Summary

- Meaning of STEAM-ED
- Social Constructivist Theory
- Issue of Disciplinarity in Education
- Contrasting Multidisciplinary, Interdisciplinary and Transdisciplinary
- Introduction to Transdisciplinarity
- A STEAM-ED approach through transdisciplinarity
- Transdisciplinary inquiry
- Transdisciplinary skills
- Example of Transdisciplinary STEAM-ED.

Recommended Resources

(Nil).

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