Early Child Development and Care

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gecd20

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To cite this article: Mike Watts (2021) Friedrich Froebel: interpolation, extrapolation, Early Child Development and Care, 191:7-8, 1186-1195, DOI: 10.1080/03004430.2021.1881077

To link to this article: https://doi.org/10.1080/03004430.2021.1881077

Published online: 13 Feb 2021.

EARLY CHILD DEVELOPMENT AND CARE
2021, VOL. 191, NOS. 7–8, 1186–1195
https://doi.org/10.1080/03004430.2021.1881077

Friedrich Froebel: interpolation, extrapolation

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ABSTRACT

Fredrich Froebel was a scientist, both in instinct and in training, and his life coincided with an important and dynamic period of scientific growth. I take this opportunity to delve both into some history and futurology to examine the heritage and legacy of his work. The usual of interpolation is of reading into data: where there exist some consistent trends within a broad set of data then the reader can reasonably infer the value of intervening points, to 'read between the dots.' Here, I explore known features of Froebel's scientific life and then read – interpret – between the lines. Extrapolations, in turn, are inferences made beyond the data, surmises drawn from datum points already established. This is 'informed speculation'. In the latter part of the paper, I run with some of Froebel's seminal ideas into the near future, peering forward for issues in science education that might plausibly have Froebelian antecedents.

ARTICLE HISTORY
Received 18 January 2021
Accepted 20 January 2021

KEYWORDS
Froebel; science; inquiry-based learning; sustainable development

Introduction

Much has been written about the educational philosophy and practice of Friedrich Froebel and his impact upon educational developments across the world (c.f. Bruce, Elfer, Powell, & Werth, 2019). In this paper I take a particular perspective on his life and look at 'Froebel the scientist'. He was indeed a scientist, both in instinct and in training, and his life coincided with an enormously important and dynamic period of scientific growth. My own background lies in science education and this is an indulgent opportunity to delve both into some history and futurology to examine this aspect of the heritage and legacy of his work. The usual 'science sense' of *interpolation* is that of reading into a collection of data: where there exist some generally consistent trends within a broad set of data then the reader can reasonably infer the value of intervening points, to 'read into the gaps', 'read between the dots.' I do so here by exploring known features of Froebel's scientific life and then reading – interpreting – between the lines. *Extrapolations*, in turn, are inferences made beyond the data, surmises drawn from datum points already established. This is 'informed speculation'. In the latter part of the paper, I run with some of Froebel's seminal ideas into the near future, peering forward for issues in science education that might plausibly have Froebelian antecedents. There is no doubt that his work in science powerfully shaped his educational thinking: it is this shaping – and forward-shaping – I explore here.

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Interpolation

Born in 1782, Froebel entered the world during an explosion of scientific discoveries and advances that moulded his life and became imprinted throughout his educational philosophy. He left elementary school at age 15, by which time he had acquired a penchant for mathematics and a love for nature. In his early teens he lived with his uncle and worked with a forester in Germany's Thuringian Forest, taking care of animals and trees (Liebschner, 1992). At the end of his working day, left very much to his own devices, Froebel spent his evenings in self-study of botany and mathematics courtesy of his uncle's extensive library.

The year 1800, the turn of the nineteenth century, aged 18, he set forth from home in possession of piecemeal school studies, a fierce love of nature and mathematics. His strong urge was to study natural sciences in a search for nature's universal laws and feed his tendency to seek general truths from serendipitous observation of nature, especially from plants and trees. Even at this early age he was looking for general laws to explain most, if not all, natural phenomena. He believed that botany and mathematics must be studied in tandem, so that he developed knowledge of arithmetic, algebra, geometry alongside mineralogy, natural history, physics, chemistry and architecture. In his autobiography Froebel says he was struck at that time by two key principles, first the conception of the '*mutual relationship of all animals extending like a network in all directions*' and, second, that the '*skeleton or bony frame work or fishes birds and man was one and the same plan*' (p36).

This study of comparative anatomy and physiology to which Froebel refers had reached new heights at the time. It was a period of intense political and social upheaval. Revolutions were in the air, as were declarations and constitutions of individual rights. The French Revolution had barely ended, George Washington had recently taken office as the first President of the United States. The impact of the French Revolution and Napoleon's reign pervaded daily lives across continental Europe and they were felt, too, across the Atlantic in the newly united American Republic. In 1803, for example, President Thomas Jefferson bought the Louisiana Territory from Napoleon's France, effectively doubling the size of the country, sparking a furious land-grab and unprecedented civil development.

By this point in the early part of the nineteenth century, natural sciences had begun to take on institutional and public authority, and to adopt burgeoning powers. Froebel's immersion in the sciences of the day was fundamental to the 'naturalistic' shape of his educational practice, and to the 'gartens' in which his kinder would eventually be nurtured and grow (Brehony, 2001; Downs, 1978). Beginning around the 1770s, forestry – and botany more broadly – had become a popular 'craze' in Germany. Up to this point the biological world was *relatively* unexplored, although this was changing by the day. At the turn of the nineteenth century, there was a clear and emphatic emphasis on travel – the great explorations of the world were in full flow. Cook's famous expedition to the Australia and New Zealand took place, along with Alexander Humboldt's 'opening up of the Americas', not least his travels to South America with Simon de Bolivar. When the English geologist Charles Lyell was asked by a young student for three words of advice he replied: 'Travel, travel, travel' (Porter, 1978). At this time in history, travelling served – as it always has done – to satiate curiosity and to fulfil youthful dreams. Natural history was an attempt to describe, to classify and to map all realms and nature through spatial arrangements. For example, when Humboldt first landed on South American soil, he was overwhelmed by the newness of what he saw:

> In the first three days, we could not proceed with any scientific work. We would pick up an object and within seconds rejected for a more striking one (De Terra, 1955, p. 75).

On September 1st, 1800 Humboldt counted that they had already collected more than twelve thousand plants. Humboldt was less jubilant than nervous. To add so many things to the store of human knowledge of nature was a marvellous achievement and at the same time a threat to the capacity of human understanding. Each day, traditional schemes of classification had to be enlarged and established nomenclature had to be changed. When Humboldt was planning to write a history of plants, he really meant to write the *geography* of plants, by describing their distribution on Earth. This travel frenzy was characteristic of Humboldt and of his time: one had to see everything and have travelled everywhere if one wanted to uncover nature's secrets. Humboldt travelled to Venezuela, Colombia and Peru, to Mexico, Cuba and to the United States with a firm plan to return home via Asia and Africa.

Cook's voyage in the Endeavour brought back to England, via Botany Bay, some thirteen hundred hitherto unknown species of plants thanks to the labours of Joseph Banks, the young botanist who accompanied him. The founding of the Royal Botanic Gardens at Kew was a monument to this new enthusiasm for greenery. The great Swedish botanist Carl Linnaeus had introduced the system of modern plant classification in the middle years at the eighteenth century (Parker & Ross-Jones, 2013). An extensive catalogue of the Breiter gardens at Leipzig, with its many hothouses, lists 9800 plants growing in the garden, amongst them many exotic plants, the book being dedicated to the Grand Duke Carl August.

This was the world that shaped the young Froebel. His father died in 1802 and Froebel was required to manage for himself. He was raised in an environment where empirical knowledge was valued as much as theoretical developments. Gottlob Werner, a German naturalist said at this time:

> Go my Sons, buy stout shoes, climb the mountains, search the valleys, the deserts, the sea shores, and the deep recesses of the Earth. Look for the various kinds of minerals, note their characters and mark their origin. Lastly, buy coal, build furnaces, observe and experiment without ceasing, for in this way and in no other will you arrive at a knowledge of the nature and properties of things (Schneer, 1995, p. 175).

This would have been a call close to Froebel's heart and it was some time before he found his true vocation. For the next three and a half years he was to travel, finding work in one part of Germany or another, sometimes land-surveying, sometimes acting as accountant, sometimes as private secretary. With great difficulty he managed to join his elder brother at the university of Jena and for a year he went from lecture to lecture hoping to grasp connectivity between the sciences – he saw connections to be far more attractive than any one science in itself. Froebel's allowance of money was small, his skill in the management of money even smaller, and his university career ended in imprisonment for nine weeks for a debt of thirty shillings. He returned home with poor prospects but seriously intent on a course of 'self-completion' – continuing his own autodidactic studies.

Froebel the mineralogist

Froebel was building a philosophy that shaped his way of life. Holding that since man and nature were derived from the same source, God, they must then be governed by the same laws. He longed for more knowledge of natural science and decided to resume a university course so rudely interrupted eleven years before. In 1811 he began studies at Gottingen, from where he proceeded to Berlin. His studies were interrupted a second time, at this point by the Napoleonic Wars, when he enlisted in Lutzow's corps and survived the campaign of 1813. At the peace of Fontainebleau signed in 1814, Froebel returned to Berlin and became curator of the Museum of Mineralogy under Professor Christian Weiss.

Humboldt had founded the Berlin University, now the Humboldt University, in 1810 and mineralogy became a natural science taught at the University. In 1814, the University acquired the Berlin mineral collection and moved it to its main buildings located on the famous Unter den Linden avenue. The collection was renamed Mineralogical Museum of the University. Berlin was very prominent in the 'Golden age of Geology', with German naturalists and explorers leading in both theorizing and investigating. The Berlin School, as it became known, was a major centre of geological theoretical paradigm change – an intense debate raging between Plutonistic and Neptunistic theories, related to the formation of the Earth's surface. Froebel, then, was working at the very heart – one might say the epicentre -of the major geological theoretical controversies of the time. He took this work seriously and, in 1816, he was offered the post of curator of the newly opened Mineralological Museum in Stockholm.

It was early in the age of steam – which increased the possibilities of travel so that even in Froebel's lifetime came the building of great railways across Europe and the north American continent. It was time of great excavations, for mining, prospecting for ores, travel, road building, for canal building, and steam engines were already in familiar use for transporting men and machinery from the surface down the coalface and in pumping out water from deep mine shafts. Numerous plans and drawings were made, showing the ways in which the Earth's surface is stratified and pockmarked with a range of features. In this moving of the Earth's surface many mineralogical finds, discoveries and theories were made. Germany had a long tradition of mining, not just for coal but for many other minerals. The words 'minerals' and 'mining', of course, have the same etymological roots and it was common knowledge in mining areas – like Thuringia – that, as one digs down through the earth, one encounters different layers, patterns of strata containing different kinds of rock and soils and, of course, fossils.

In France, Antoine-Laurent Lavoisier was becoming the greatest chemist of the eighteenth century. Before this, while his chemical interests were still growing, he worked with Jean-Etienne Guettard, a geologist mapping the geology of France. It is thought that Lavoisier deduced the vertical succession of rock strata from the map distribution of rock-types and hence translated the geometry of the time into a sequence of past events, represented by the succession of rock strata. Lavoisier began sorting out chemistry through a system of classifying compounds through the elements they contained. He revolutionized chemistry and provided the first list of elements and their new names. He was working on this up to the point he was beheaded on the guillotine in the latter stages of the French revolution. As an aside, it is interesting to note that Lavoisier was a landed gentleman and farmer, and he married when his wife was 14 and he in his 40s. With Lavoisier guillotined, Marie-Anne went on to marry the American physicist Benjamin Thompson (Count Rumford) and together they published Lavoisier's *Memoires des chemie* (Brown, 1967). When married to Lavoisier, Marie-Anne had enjoyed a very high standard of living and of entertaining in the highest social order. Her marriage to Benjamin Thompson was considerably less successful – he was an adventurer and self-styled Count and a lot less wealthy. When she was unable to maintain her high standards of living, she threw out his rock samples and poured boiling water on his plant collection. They were divorced shortly afterwards.

In the 1780s a slab of chalk with giant jaws was discovered in a chalk quarry in the town of Maastrict in the Netherlands, just before the town was sacked by Napoleon's army in 1795. It was described by the great French anatomist Georges Cuvier in 1808 as a giant extinct marine lizard. He named it the *Mosasaurus* (or Meuse lizard) from the Meuse River near the town of Maastricht. Cuvier was correct in his interpretation and this was no dinosaur. Cuvier studied fossils and realized that the Earth's history is documented in the fossil strata and noted the unique set of fossil species in each stratum of sedimentary rock. He also noted that older (deeper) strata had forms most different from modern species and realized that extinction is common in history of life on Earth. It was a pre-paradigmatic period of science; the really great advances in chemistry were yet come – as was the publication of Charles Darwin's *Origin of species*. There was an enormous debate around the content and practice of science without – yet – the resolution of many issues and problems through overarching theory. It was a period in which the study of nature was carried out between the extremes of lofty thinking and speculation on the one hand, and experiment and calculation on the other.

Froebel was steeped in this kind of debate. His work at the mineralogical museum at Berlin entailed classifying minerals according to the geometry of their crystals. In his autobiography, Froebel said:

> The world of crystals proclaimed to me in distinct and unequivocal terms the laws of human life […] What the spiritual eye sees inwardly in the world of thought and mind, it sees outwardly in the world of crystals (p.156).

The system he used was a complex interweaving of observations. It was important, he said, that ideas be presented sequentially in order to develop the skills needed to see not just the appearance of things but the things as they are, to see not just the contained but the container. The connections, the containment, were important – not just the things themselves but that which connected them – and later became the theoretical basis of his 'gifts' and 'occupations'.

It is important, too, to discuss Froebel and science in relation to two major schools of thought, those of Humanism and Romanticism. The eighteenth century was pre-eminently the age of Enlightenment that sparkled in France, then the centre of European culture. French intellectuals, or philosophers, had the deep conviction that reason and science, if allowed freedom of expression, would inevitably produce a new and enlightened outlook. They believed in freedom of thought, in tolerance, in reason, in science and in progress. The salons of Paris were 'clearing houses' of ideas, exchanged with brilliance, wit and urbanity. In the wake of the French revolution Frankfurt became the seat of German liberalism.

For both the advocates of a humanistic and a romantic philosophy there are natural laws similar to the law of gravitation in physics: laws that drive psychology, political science, economics, history and religion. One debate concerned the nature of progress – did it evolve naturally or was it part of a grand design and plan? At about 1800 the evidence of a 'plan' in the structure and relationship of living organisms was often taken to show that there was a grand design underlying the universe and its creatures, a design that had nothing to do with evolution. The idea of 'nature' became a substitute for ethics and theology. 'Nothing that exists can be against or outside nature' wrote Diderot (McKenzie, 1960). Rousseau popularized the idea of the natural, noble Savage (Cranston, 1999).

Both the Humanists and the Romantics believed that individuals strive for self-realization, self-actualization and self-fulfilment. People have a great potential to comprehend themselves, to alter their self-awareness and to display self-directed behaviour. Froebel followed Rousseau in believing that children actually want to learn, and that effective learning is through activity. Froebel's philosophy of education incorporated many of these ideas, but his sense of self-fulfilment had little in common with, for example, the Romantics' notion of unfettered individualism. His 'Spherical Law' recognized that the sphere contained all basic laws relating to the universe, the physical, the moral, the intellectual, the feeling, thinking – and psychical – world. Man is a member of a larger whole, a part of something greater than himself, a family, a community, and his growth and development must be seen in relation to these larger units. Froebel's 'law' recognized the unique freedom of each individual but only in as far as this contributed to the laws of nature, which is unity. Individual differentiation can be seen only in terms of the totality to which it contributes. This is a further expression of the parts-and-whole emphasis within the science of the time.

Over this period, the Romantic movement turned into a revolt against rationalism and stressed sentiment rather than reason. Humanists, on the other hand, acknowledged the astonishing success enjoyed by the natural sciences in creating universally accepted 'factual' knowledge. However, they maintained that this success carried a cost, at least in educational terms. It implied a cumulative body of authoritative knowledge to be taught. The authority of that knowledge effectively denied the students intellectual independence, placing them in a position of relative passivity. In addition, the materialism under which natural science understood the world constrained its engagement with ethical, aesthetic and similar humane domains. While the possession of such characteristics did not render natural science unfit for a place in the curriculum, it did invite a critical attitude towards it. In contrast, the defenders of science believed that, through science, they could deliver all of education. It promoted, they argued, awe and admiration, emotions, relationships, moral agency and promoted insight into fellow human beings. Science it was believed, would teach man to behave naturally – the natural and rational environment would enable man's innate goodness to develop towards happiness and perfection.

Momentary pause: so, what survives – and derives – from this backdrop?

There have been, and will continue to be, furious debates over the forms and function of education. 'Traditionalists versus progressives' occupies a very old battleground, but one that endures nevertheless, reappearing with grinding regularity. It is a debate likely therefore to loom large over and again into the future. I am no neutral bystander, I am certainly no traditionalist and, in terms of science education at least, am enormously sceptical of the value of traditional content-based school education. This is true for early childhood nurseries every bit as much as for secondary and pre-university schooling.

It is somewhat passé to argue that much of Froebelian thinking has now been absorbed in to 'good practice' in mainstream early years education (Bruce et al., 2019) and is present in early schooling in essence if not in name. While child-centred learning is honoured these days more in the breach than in the observance, it is still usual for Froebelians to point to the commonality of play in itself, of play-based curriculums, outdoor play, vegetable gardens, mud kitchens, sand and water tables – and certainly to block play. Froebelian and 'sister' Montessori, Pestalozzi, Regio Emelia and Steiner schools are still to be found dotted around the world and, more currently, the Forest School movement extols the virtues of learning through outdoor nature. It is not mainstream schooling, though, that interests me here – Froebel himself was most certainly a 'progressive' – and I could have drawn many strands from his work, consistent and developed themes within the data of his life, to allow extrapolation beyond his time. I have chosen six.

First, Froebel's was an ecological view of mankind in the natural world. He applauded the uniqueness of each child's capacity and potential, held a holistic view of each child's development – both as an individual and as part of a community. His was a recognition of childhood in its own right – a recognition that, in order to be educative, the child must have a sense of the purpose, meaning and joy of activities – and that they involve, wonder, concentration, unity and satisfaction.

Second, all learning must begin with the learner. It was an approach to learning that recognized children as active, feeling and thinking beings, seeing patterns and making connections within their own lives. He believed in freedom of action within the overall constraints of learning. He wanted to free children from drudgery and rote memorizing. Learning, he thought, succeeded best when undertaken by the curious self-active mind, his educational work was geared to making children think. Freedom for children to explore, choose and question would result in responsible actions and this freedom was not in opposition to order and harmony – discipline was a non-issue in a well-conceived educational programme. It was an approach to learning that developed children's independence sense of mastery.

Third, he advocated a problem-solving approach to learning. Froebel would often present children with genuine, 'authentic', problems and then leave them to solve these in their own time and ways. Once a problem was solved, Froebel would return, show great pleasure in the individual solutions, give new ideas and inspiration, and then depart once more, leaving the children to find further answers. He liked them to take things apart and analyse the 'basic' components, to observe and record observations and then try to re-constitute the basic parts together again within some theoretical perspective. Throughout all of this, he emphasized creative play. It was an approach to learning that used first-hand experience, talk, Individual and collaborative play and reflection as media for learning.

Fourth, education of this kind required knowledgeable and appropriately qualified teachers and nursery nurses – a sound knowledge of children was a prerequisite for successful teaching. Education related to all faculties and abilities in each child: imaginative, creative, linguistic, mathematical, musical, aesthetic, scientific, physical, social, moral, cultural and spiritual. The study of science, often in the form of nature, design, construction and mathematics was an integral – if not central – part of the curriculum for each child. Skilled and informed observation of children underpinned effective teaching and learning; a system based on encouragement rather than punishment. In Froebel's time, the teacher's task was to ensure 'freedom with guidance', so that creative play corresponded to each child's developmental needs and interests, commonly using the 'gifts' and 'occupations' that he designed.

Fifth, he emphasized the importance of the family in learning, particularly for very young children. This was, perhaps, a sense of compensation for his own rather lonely upbringing. He wanted parents and educators to work in harmony and partnership, stressed the importance of mothers caring for their children, teaching them to be observant and attentive. Froebel had an enormous effect in establishing the professional foundations for many women in developing careers as skilled kindergarten teachers, being 'efficient mediators between the mother and child' (Froebel, 1887). He described this close partnership as promoting independence as well as interdependence, individuality as well as community, freedom as well as responsibility. It was a demonstration of education as an integral part of the community it serves.

Finally, he saw the location, the 'site' of learning to be important. For this, in 1837, he created 'kindergartens' – children's gardens. These were designed to be physically safe but intellectually challenging, promoting curiosity, enquiry, sensory stimulation and aesthetic awareness. His idea was that children could play freely and observe and interact with nature away from adult imperatives, to allow free access to a rich range of materials to promote open-ended opportunities for play representation and creativity. This was extraordinarily progressive in an age when children were expected to behave as miniature adults.

Extrapolation

In looking forward, I choose just three (of many) areas of future science education that might be viewed through a Froebelian lens. I have contained these within science education rather than education more broadly and have felt unconstrained by age or stage in learning-life. Before I look forward, the 'platform' I adopt is based on a number of premises:

1. Formal school education entails just 15% of an average life-course (much less, in some cases) and so at least 85% of a person's three-score-years-and-ten-learning takes place in his or her informal everyday lived experience and away from formal institutions (school, college, university). In their (in)famous book on education, Postman and Weingartner (1969) said:

   School is the one institution in our society that is inflicted on everybody, and what happens in school makes a difference – for good or ill. We use the word 'inflicted' because we believe that the way schools are currently conducted does very little, and quite probably nothing, to help us solve any or even some of the [world's] problems (p.xiii).

   My own views on this are clear: even at 15% of one's life, schools are no better now than they were in 1969 in tackling major problems such as, for example, climate change.
2. We educators are fortunate if ANY subject knowledge is retained (say) twelve months beyond the cessation of formal study and assessment. We are doubly fortunate if learners are sufficiently skilled and motivated to transfer some of that knowledge from one context to another, for example from one subject domain to another, let alone one physical (classroom) context to another (workplace). The best we can hope for is that learners develop robust self-confidence, self-efficacy and self-direction in learning to last their lifetime.
3. While teaching might be seen as a process of layering, sequencing, contextualizing and presenting a considered and bounded body of knowledge, learning seldom replicates such hierarchies, linearity, timing, boundaries or implications. While teaching looks to build structured knowledge, learning entails a process of individually structuring meaningful knowledge – in very personal and idiosyncratic ways.
4. From my perspective, formal science education has little if anything to say about generating a cadre of elite scientists. Professional scientists on the whole become scientists despite rather than because of their early schooling (Salehjee & Watts, 2020), and the routes involved are not particularly interesting here. My own work is directed much more towards the public understanding of science (PUS) and the development of broad and general science literacy. I am interested in greater public inclusion in science through, for example, public appreciation, participation and engagement with science and technology – through 'science for all'.

Perhaps unsurprisingly, then, my first look ahead comes through what has been called 'free-choice learning'. John Falk and colleagues (e.g. Falk, 2006; Falk & Storksdieck, 2005) have shaped ideas and research around the public's free-choice informal learning in science – distinct from formal learning in that it maintains a powerful element of personal choice and control. Learning in the 85% of non-institutional life (Falk actually calculates it at 95%), individuals engage in free-choice science learning for many reasons – to satisfy, for example, a personal sense of identity and identity transformation (Salehjee & Watts, 2020), to fulfil personal intellectual and emotional needs (Dirkx, 2001), to create a sense of value within the world and to create greater sense of community (Biesta, 2012; Gherardi & Perrotta, 2014). Free-choice science learning typically plays out in people seeking to fulfil short-term personal intellectual and emotional needs (Watts, 2015), rather than striving for accreditation or to satisfy longer-term occupational duties in science or technology. Many of the studies of free choice learning in this context occur in family groups in settings such as national parks, conservation centres, science museums (Kanhadilok & Watts, 2017), aquariums, botanical gardens, planetariums, space centres, science exhibitions, galleries, outdoor study centres, amateur astronomy clubs, popular participative programmes such as Springwatch, Birdwatch, Makerspace, special interest groups and many – many – more such arenas. This provides meaningful enjoyable opportunities and experiences alongside risk-taking and challenge and represents learning science out in the 'real' world as we know it today.

For me, this is the future for science literacy, though there are also other ingredients in the mix. One of these is the advent of the smartphone: smartphones are distinct from other technological devices in their comprehensive and advanced features, such as Wi-Fi connectivity, high-resolution touch screen displays, web browsing capacity and sophisticated built-in applications. They have the capacity to run numerous applications, transforming the humble single-purpose phone into a powerful, multifunctional and affordable 'computer'. To a large extent, smartphones are redefining informal free-choice learning by supporting learners in assessing meaningful and diversified resources from both the real and virtual world, enhancing mobility, providing greater accuracy of location for contextual learning, enhancing availability and access to information. This kind of science learning has a distinct level of non-linearity through the watching of television, podcasts, YouTube, films; reading magazines or pamphlets; learning in the workplace or using an array of digital media such as the Internet, social networks and games. It is a move to a multi-literacy approach that allows for imagination, creativity, and symbolic complexity in science learning (Facer, 2011). In my view it represents a clear move from instructional didactics towards a learner-centred heutalogical approach.

Is any of this remotely Froebelian? Yes, very much so in spirit. While the 'natural world' is changing around us, the fostering of individual meaning-making through edicts to 'go forth and find out' are alive and well. His Museum of Minerology has been joined by a vast array of science-based sites of information, curiosity, enjoyment, challenge, fun and creative play. Moreover, people at large now have readily available tools through which to access these and much more, both through physical and virtual reality. These tools have taken over from his gifts and occupations as a series of devices and activities intended to introduce learners to the physical forms and relationships found in nature. In my view, alive today, Froebel would have recognized the 'gifts' of free-choice multi-literacy learning.

My second 'future pointer' is towards inquiry-based learning (IBL), and particularly educational moves towards problem-based learning (PBL). IBL is an approach in science education where learners adopt and adapt the methods and practices of science to re-construct principles and concepts, thereby, actively constructing their own knowledge (Lehmann, 2018; Van Joolingen, De Jong, Lazonder, Savelsbergh, & Manlove, 2005). PBL, in turn, has roots in a general model within medical science education in the early 1970s and has since spread to many curriculum areas (Savery & Duffy, 2001). Some of the features of PBL are that the learners are actively engaged in working at tasks and activities which are 'real world', authentic to the environment in which they are to be used. The focus is on learners constructing their own knowledge in a context similar to the one in which they would apply that knowledge. Students are encouraged and expected to think both critically and creatively and to monitor their own learning and understanding. Project-Based Learning tends to be a group activity with timelines, milestones and other formative evaluation steps. The intentions behind both IBL and PBL, then, lie in educating students to identify learning issues for themselves, go through that learning, solve and then implement various solutions to the problem together with members of their team. They are educative processes that promote the need to equip students to become change agents able to deal with complexity and soft, human as well as hard, technical issues. They are commonly seen and described as important twenty-first-century skills (Jang, 2016). Froebelian? Very much so.

My third pointer is towards sustainable development. We live in an 'anthropocene era', in which – as in Froebel's day – human activity plays an enormous role in determining conditions on the planet. Species survival requires monitoring, understanding, forecasting, mitigating and adapting to changing social, economic, biological, geological, and physical conditions around us. Successfully addressing these challenges requires a continuously iterative process of learning, building, integrating, and using knowledge, including that of natural and social science and humanities. This presents new challenges that require a restructuring of the purpose, content, and approaches to education. The UK's Environmental Protection Agency has pointed out that:

> Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony that permit fulfilling the social, economic, and other requirements of present and future generations (p17).

This is in concert with the United Nation's 2030 *Agenda for Sustainable Development,* which has argued that all people need to acquire knowledge and skills to promote sustainable development. My focus here is on changes needed in order to contribute to a sustainable future and, in my view, science education is challenged by the UN's sustainable development goals (SDGs) to find effective means to integrate scientific knowledge and skills into real-world situations and build sustainability-relevant values and attitudes. In doing so, science educators must cross disciplinary boundaries – find connectedness – to solve environmental problems. Is any of this Froebelian? Yes, very much in spirit. This kind of cross- and multi-disciplinarity was a long-held key Froebelian principle around connections and connectivity, especially with regards to nature.

Final comments

Scenario building is an inexact art. It is rarely a tool around which to build consensus and I am certain there are many Froebelians who shiver at the directions I have taken. This is a single vision into complex social pasts and shifting futures. As Peter Weston (2002) points out, Froebel himself was concerned to protect young learners 'from the garments of custom and ancient prescription', and the principles and practices deriving from Froebelian values are dynamic and developmental.

Disclosure statement

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

Notes on contributor

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