Pedagogical Research
2019, 4(2), em0032
ISSN: 2468-4929

What we Teach in Science, and What Learners Learn: A Gap that Needs Bridging

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Citation: Iwuanyanwu, P. N. (2019). What we Teach in Science, and What Learners Learn: A Gap that Needs Bridging. *Pedagogical Research*, 4(2), em0032. https://doi.org/10.29333/pr/5780

Published: May 14, 2019

ABSTRACT

As long has been known, there is no perfect way to teach science. This paper makes no claim to be the 'be-all and end-all' of science education. Rather it critically examines what we teach learners in science and what they learn and tries to offer suggestions that can help teachers to surmount the scholastic inadequacies they tend to encounter in teaching science. Going beyond previous literature, it asks why we teach science, and why is science included in the school curriculum. From a theoretical perspective, the answers given to these questions follow the line of certain recent work in science education. The paper attempts to explain the answers, extending an argument based on the author's personal opinions, according to which these recommendations are offered: a) pedagogical innovation can mitigate some of the challenges today's learners are facing in learning science, b) engagement in scientific practices with focus on explicit discussion and reflection upon inquiry experiences needed to build understanding of the nature of science tenets has the potential to improve and increase learners' science learning, and c) all countries will face consequences if today's science learners are not adequately prepared to collaborate and resolve the ever-expanding global, diverse, and technical economy challenges.

Keywords: science, learners, curriculum, teachers

INTRODUCTION

In today's science world, teachers, instructors and faculty in places of teaching and learning are finding it difficult to manage pedagogical practices at the speed of learner's life world, with often larger classes, more diverse learners, demands from school authorities who want more accountability and the development of 21st century science graduates who are workforce ready in a competing fourth industrial revolution (4IR) era. To handle change of this nature, science teachers and instructors need to transform their pedagogical practices to involve decisions about what to teach in science lesson activity, what learners learn, why teach it, and how can it be presented to help digital and social generation of learners better understand it, and above all, improvisation among other things. For that to happen, there is a great need for substantial reform in science pedagogical practices to suit today's learners. This coupled with other concerns has been the focus of recent and urgent calls made by science education researchers and reformers in the extant literature. This paper adds to that call. The paper is divided into two parts: part one critically examines what we teach our learners in science, and part two explores what learners learn. Further to this, the paper attempts to identify gaps and use relevant literature to further our understanding of how the identified inadequacies (or gaps) can be bridged. Thus, the paper provides suggestions that could help science teachers and instructors to reconsider their goals and pedagogical practices. In addition, the paper identifies the key knowledge and skills that today's learners need in a digital age, and how information and communications technology (ICT) is changing everything, including the context in which we teach science.

Given the emergence of the fourth industrial revolution (4IR) and the importance of science and technology in contemporary society, and given its implications in what today's learners are taught in science and what they learn, it is astonishing that the area this paper is canvassing has been so neglected. Presently, the revolution of digital and social-media age has taken many of us by surprise. Our life world is changing. Traditional pedagogical practice can no longer manage the speed of today's learners' life world. Modern science is becoming more sophisticating. However, pairing this change with new teaching and learning practices of science is essential to realize its potential. Soon the future of science teaching and learning processes around the world will inevitably take place in environments (**Figure 1**) where learners select their own modes of learning and bring personal technologies into education (Mynbayeva, Sadvakassova, and Akshalova, 2018; UNESCO, 2013a).

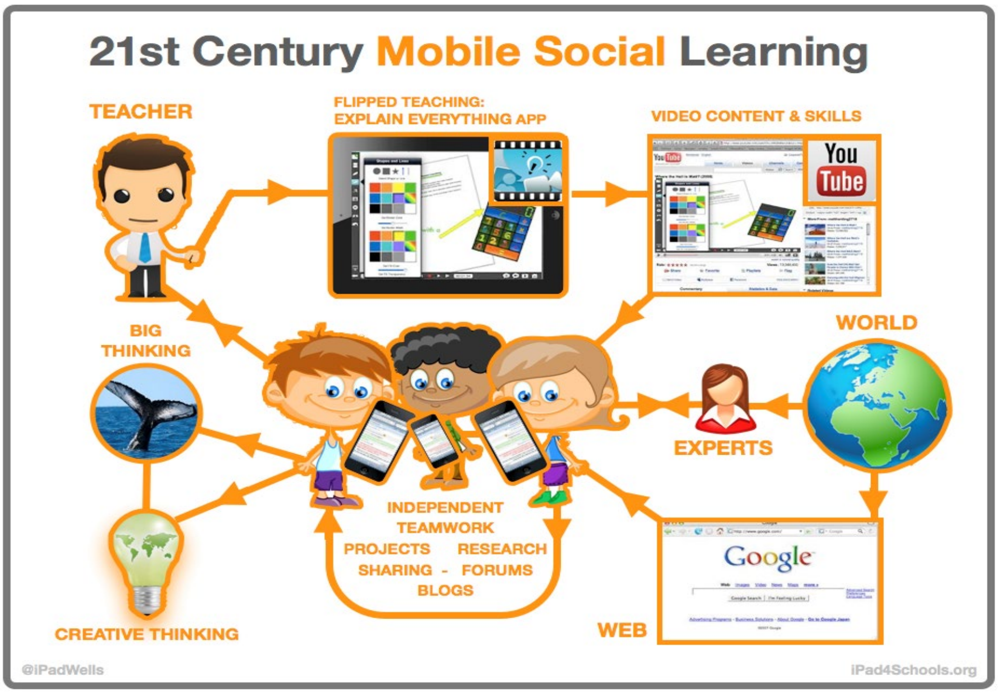

Figure 1. Learning in digital and social-media age
Image: Eduwells (2012). Retrieved from https://eduwells.com/poster-21st-century-mobile-social-learning

Therefore, as the gateway to cultivating creativity and innovation, an understanding of what we teach in science, and what learners learn is essential for success and productivity in modern science (International Council for Science [ICSU], 2011). In view of the already existing subject imbalance among the teachers of science to this age-group, it must be of some interest to shed some light on the history of science and nature.

INSIGHTS FROM THE HISTORY OF SCIENCE

It is difficult to imagine a narrower conception of what science is and how best to present satisfactory insights from its history. Countless examples could be given of what science is and its history. But perhaps a consideration of the nature of science and the general belief that science consists of a body of knowledge about the world serves as a point of departure. Such a view persists not only among the general public, but among science teachers, science education researchers and scientists (Yore, Hand, and Florence, 2004; Zeidler and Abd-El Khalick, 2017). The facts that comprise the scientific body of knowledge are derived from accurate observations and careful experiments that can be checked by repeating them. Since man's earliest existence, he has studied science intentionally or unintentionally in an attempt to improve his knowledge of the natural world and the mystery of the universe. Searching for answers to the questions about his place in the universe and the mysteries behind natural phenomena, man invented a way of thought. He had to work out a way of thinking that would satisfy his curiosity and give him reliable answers. This way of thinking, resulting from man's search for reliability, is called scientific thinking (Kuhn, 1970).

At first, man began with observations of nature, as we do today, and went on to gather information and apply it to his daily life. That was approximately the position of many philosophers, e.g., Aristotle, Ptolemy, Copernicus, Kepler, and others in the earliest centuries. These were times when everything seems totally alive, when eyes and ears and mouth drink in the world of ideas; a time when, lying on your back and looking up into the stars, you feel a sudden immediate connection to those far distant worlds, and when carried away by imaginations you ask question(s) like Mermin (1985) asked: Is the moon there when nobody looks? At these times all sorts of imagination and thought of chemical elements such as iron, zinc and chlorine were believed to be alive and have their own personalities. Then it was generally believed that events in the world were governed by the unpredictable will of the gods. Underpinned by this imagination and thought, man believed that the earth, planets and stars were regarded as spheres within spheres, all moving with uniform velocity; this must be so, he said, since the most perfect of all bodies is a sphere and the most perfect motion is uniform motion (Heisenberg, 1958). Then man could theorize that the activity in a pot of boiling water is due to invisible powers of gods or some spirits. But the theory of the Polish astronomer Copernicus after it had been tidied up by Kepler gave mankind a new perspective of the universe (Blåsjö, 2014; Cohen, 1960). Copernicus initiated a revolution in astronomy by proposing that the sun is at the centre of the universe. With this new idea, he was able to explain the existing data which opened the flood gate to a new hoard of scientists. Likewise, Galileo gave mankind the principle of experimentation concerning the laws of motion which helped further the understanding of the universe (Finocchiaro, 2002). His data led him to question the current belief of the time that all things revolved around the Earth (Lucretius, 1986). Gradually, progress was made and man's understanding of the natural phenomena continued to shift away from mere subjectivity toward objectivity, reproducibility and experimentation.

As time goes on, new observations about the universe and natural phenomena were made, new measurements were checked, and new scholarly papers were written. During this period, formal attempts were made to provide accurate descriptions of the universe through scientific reasoning (Penrose and Mermin, 1990). The lessons learnt from the study of astronomy gave rise to natural philosophy, i.e., the science of chemistry, physics and biology. The new point of view ultimately led to rapid progress in the understanding of natural phenomena. This was the beginning of the scientific revolution (Kuhn, 1970). Today, the development of modern instruments ranging from those that allow us to see minute particles of matter magnified millions of times to those that enable us to see distant stars on the outer fringes of the universe as we know it have been made. This achievement has brought great advances in man's understanding of his world and the nature of science. With this, to some extent man has cracked the code of answers to the perennial questions about the vast nature of the universe. He can now apply his gained knowledge and learned skills to solve a wide range of scientific and technological puzzles of the 21st century.

WHY IS SCIENCE INCLUDED IN THE SCHOOL CURRICULUM?

A number of points have emerged from the above discussion from which we can draw reasons why science is included in the school curriculum. First, it would help man to comprehend the world around him and secondly, it would better prepare him to improve it. This further divides man's needs into twofold: Man's intellectual needs and his social needs. In terms of the intellectual needs, it means that man should experience the satisfaction which comes from intellectual engagement with the phenomena of the natural world. And for the social need, it means that man should be aware of the influence of the science on social change. Today, we view all around us the intellectual and social consequences of the applications of science in ways like never before. What ultimately makes science inevitably entangled with man's survival on earth is one of the main reasons why science should be taught in schools. In this day and age, mankind needs the services of scientists in large numbers for improving and maintaining the standard of living. The evolving capacity of science serves the need to attract some young men and women to a career in which science plays a prominent part. The ultimate aim here is to produce a community that is sensitive to the possible effects of the activities of scientists and technologists on its welfare, both now and in the future. It is in this area that the importance of science for all learners at least up to the statutory school leaving age, becomes manifest.

Science is admirably suited to showing that the pursuit of an intellectual discipline can be a pleasurable exercise. Science is fun. It has aesthetic and dramatic life-changing discoveries: for instance, the beauty of wonders of the structure of the DNA molecule (derived from Mendel's work on genetics, by Crick and Watson), the Copernicus system, law of universal gravitation by Newton, and the discovery of electricity by Faraday, Einstein's theory of relativity, Penicillin (antibiotics) by Fleming, X-ray discovery by Roentgen, quantum theory by Niels Bohr, and so on. For all these and other discoveries far too many to mention here, there are three objectives that should be borne in mind. First, science stimulates and gives intellectual pleasure that associate with it. Second, science can provide a variety of experience in posing and solving problems of real-life. Third, science is about understanding; it is one of the ways we attempt to answer the perennial questions about the natural world, our place and means of surviving in it.

There is a lesson here for science teachers. First, there must be a conscious effort on the part of the teachers and learners to relate what they do in science to the world life around them. In this sense, learning activities in science should be designed to connect learner experience to real-world problems. The claim to be defended here is that the goal of science is, in part, the gaining of knowledge, and, in any case, the acquisition of scientific knowledge is associated with processes. As we have seen, through a planned observation, reproducibility and objectivity, instead of philosophical theory and subjectivity, Copernicus and Galileo confronted nature with the principles of observations, experiments and questions. In science possibilities for error are numerous and worth investigating. Einstein, for example, showed Newton's laws to be inadequate and scientists are still testing Einstein's theories by trying to disprove or improve them. Therefore, a profoundly important dimension to science is that it is uncertain and its knowledge is constantly changing. If science is knowledge as many believe, then it is dynamic knowledge. Learners must know that science is not be-all and end-all; it is an ongoing process of knowledge building, whereby ideas, facts, laws, theories, models continued to be refined as more convincing ones emerge. Science must be seen always by learners as 'I wonder if…' If learners can be given these insights, they will have learnt science, no matter what content they have covered. In this life world, science teachers will need to transform their roles from content conveyors to content mediators (Mynbayeva, Sadvakassova, and Akshalova, 2018). In this regard, the continuity between science and nature is respected, which implies productive applicability of scientific attitudes and thinking in daily life (ICSU, 2011; Lederman and Lederman, 2014).

One thing that is meaningful, worthwhile and feasible is that science material in school curriculum should include the essential 21st century skills such as learning how to solve difficult, ill-defined problems and learning how to collaborate (Franklin, 2015; Kerchner, 2011). In science curriculum-centred approaches, a model of learning activity depicted in **Figure 2** may provide suitably motivating 'vehicles' for introducing science learners to a wide body of content from which their interests may develop.

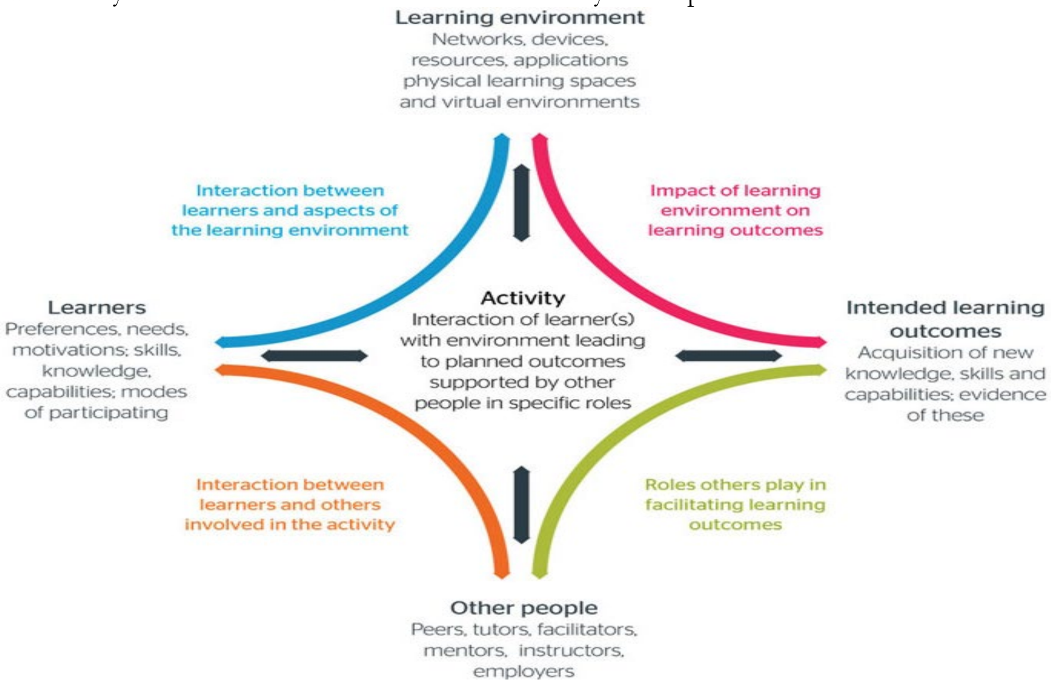

Figure 2. A model of learning activity design adapted from Beetham (2007)

Within the context of any science curricula activity, the interaction between the factors (in **Figures 1** and **2**) will be dynamic and unequal as it has the potential to engage learners' interests, active commitment and modes of learning in digital and social age. Using specific technological tools and resources, oriented towards specific curriculum outcomes, learners' needs, motives for learning science, prior experience of learning, social and interpersonal skills, preferred learning styles and expectations in science can be achieved (Beetham, 2007). However, it is unfortunate that school science curriculum as we have it in many countries often ends at transmitting scientific fixed ideas and facts, which are no more science than a heap of bricks is home. In many countries, considerable amount of the material that is presently in many science courses are tied to curricula that have not changed for twenty years or more (UNESCO, 2012; UNESCO and UNICEF, 2013a). Outcomes of these curricula have been negative in schools where learners are taught that knowledge is static and complete, resulting in which they become experts at consuming knowledge rather than producing it (Carneiro and Draxler, 2008; Zipin, 2017). Not only that science curricula activities are taught merely using transmission model, the learning outcomes present inaccurate view of how science is actually practiced, and devalues the ideas and thoughts of the individuals receiving the information (Venville and Dawson, 2010).

WHY DO WE TEACH SCIENCE?

As previously discussed, science is included in the school curriculum for a wide variety of reasons; and when justifying why we teach science, it may be useful to distinguish between reasons directly related to science itself, which point in general to its inherent value in our lives (intrinsic justification) and those which emphasize the instrumental role of science (extrinsic justification) (ICSU, 2011; McComas, 2017; NRC, 2012). Thus, science is vast, complex and interesting. In the belief that science is also comprehensible, scientists are inquisitive people who are forever trying to solve problems. Like detectives hunting for clues and building ideas and theories from them, they seek to make sense of apparent complexity of a problem by trying to relate one observation to another. The relationship, they find, are related to other relationships. It follows from this that science is taught in schools to support man's continuous search to better his knowledge of the universe, increase his awareness of the unfolding mysteries of natural phenomena, and as it is in today's age and time, it serves as an enabling tool to help man model for himself the innovative means of surviving in the universe.

Learning science provides learners with exposure to the processes of the body of scientific knowledge as featured in Figure 3. Such exposure involves confronting ideas with experience, i.e., designing investigative tasks to test ideas or hypotheses and predictions based on them (McComas, 2017). Investigative task in science provides learners with learning opportunities to practice new techniques or skills such as designing, making observation, collecting data, analyzing, synthesizing, evaluating, decision-making, problem-solving, making products, organizing and presenting results, and so on. Practice plays a very important role in the learning of these skills. In the past, however, the stress had sometimes been placed too heavily on practice and drill as the basic factors in the development and perfecting of a skill. However, it has now become clear that with an inclusion of digital (or technological) devices much time and energy can be saved in the learning of a skill (Mynbayeva et al., 2018; Twum, 2017; UNESCO, 2013a). For today's learners to learn scientific investigative skill in its functional context, in a meaningful situation, Figure 3 is proposed. It is to function as a heuristic in that it represents a strategy, independent of question content, which helps scientific problem-solvers in a digital age to approach and organize their resources in solving problems. It enables generalizations to be made about scientific procedures for alternative problems, strategies and solutions. This is important, as mentioned earlier; science is not an end in itself.

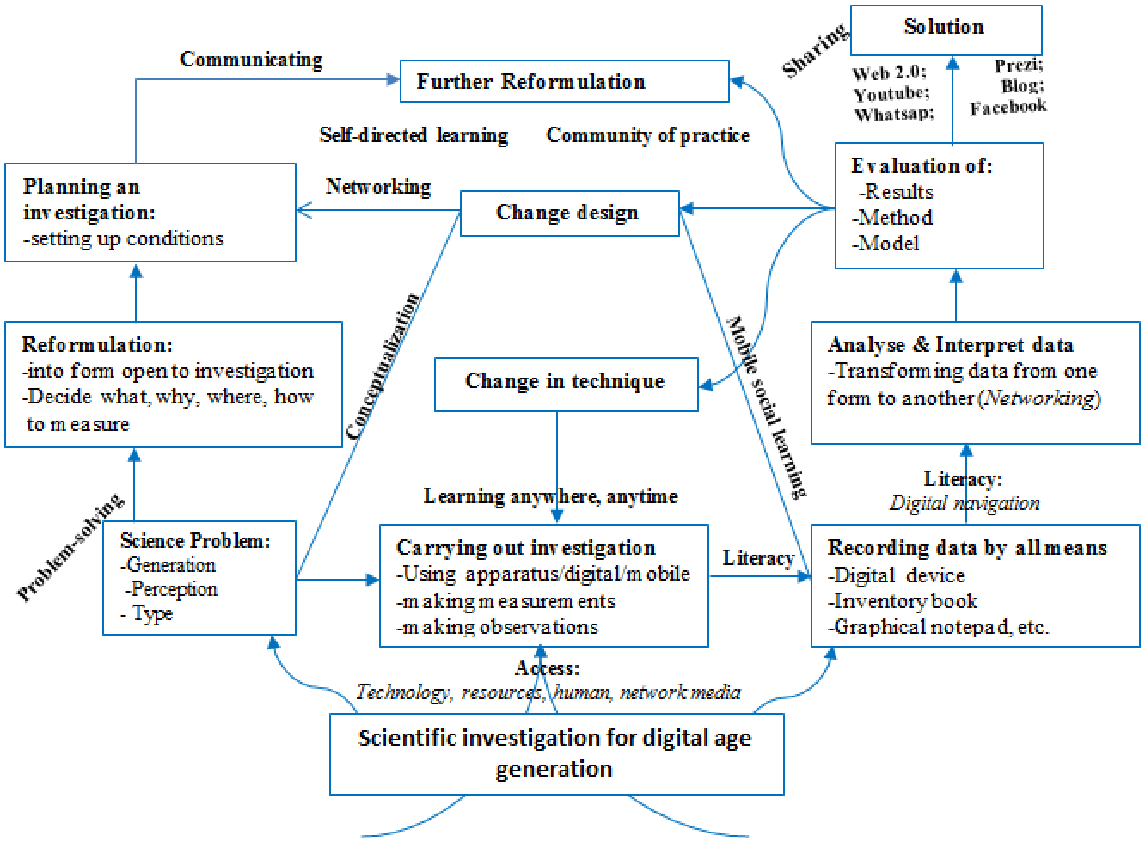

Figure 3. Scientific investigation flow chart for digital age generation

The teaching process of Figure 3 follows the stages of learning through which the digital and social age learner goes in learning a skill or technique. These stages are dynamic and flow into one another, and are not an unchanging succession or follow-up of steps. The science teacher/instructor has minimal role to play. His ultimate task is to prepare and motivate the learners to see the value laden on the problem to be investigated as well as the technique in its functional context. In following the learning process, learners work as individuals or with others (classmates, teachers, other schools, countries), make decisions, refine their perception of the problem they are investigating, collect and analyse data using choice modes, interpret results, propose an evidence-based solution and share it with others through face-to-face scientific deliberation or using wikis, blogs, discussion boards, Google docs, Skype, etc as depicted in Figure 1. Of course having said this, it must also be recognized that some learners will find their own route to the solution. This is especially the case with learners who have not developed the confidence and competence to grapple and make sense of scientific ideas. It surely must follow that the teaching of science should advocate deliberate attempts to encourage learners to stand back and look at the processes of scientific deliberation and also have set examination questions which require an understanding of the nature of science with respect to models for their solutions. Scientific deliberation begins when learners and teachers slow down the science lesson and ask what particular concepts mean and what the conditions are for their correct use. If learners must learn science, teachers must see to it that learners understand experimentation as a means of compelling nature to answer their questions. And if they are to be given the view of science of the 21st century, they must be made to appreciate the uncertainty of science, and to know that theories are speculations or guesses that must be discarded or modified as soon as they fail to fit the observations (ICSU, 2011; McComas, 2017; NRC, 2007, 2012).

Science must be seen as a way of life and not just a body of knowledge in terms of factual information that can be structured and passed on through books, lectures, and programmed courses. Understanding how science works is better portrayed through exposing learners to deep insights of the nature of science as foundation for science teaching and learning (McComas, 2017). According to Lederman and Lederman (2014), understanding aspects of the NOS has been shown to help learners to recognize the inherent values and beliefs of scientific knowledge and its development. However, what seems to matter most are the underlying impetus for changing the conventional method of teaching science to one that supports explicit discussion, questioning and reflection upon inquiry experiences needed to build understanding of the NOS tenets and make connections to scientific practices.

WHAT WE TEACH IN SCIENCE AND WHAT LEARNERS LEARN

Several international science education reforms have included scientific literacy, science practices, critical thinking, and socio-scientific issues as learning outcomes (NRC, 2012). Likewise, many countries have promoted science curricula projects oriented toward science literacy where critical thinking and problem solving emerge as prominent component (ICSU, 2011). Science has many roots, no aspects of its roots at whatever level should ignore the most fundamental strands of proficiency that learners and teachers need to cultivate. These include: 1) understand, use, and interpret scientific explanations of the natural world, 2) generate and evaluate scientific evidence and explanations, 3) understand the nature and development of scientific knowledge, and 4) participate productively in scientific practices and discourse (NRC, 2007: 334). The first strand of what we teach in science requires an awareness of, among other things, the skills to understand the core concepts of science and the explanatory theories/models in science domain and how they apply to a range of phenomena. In this sense, the teacher identifies in the science material the most fundamentally scientific ideas, and guides learners to represent what they know based on their understandings of how these ideas are connected with one another in the natural world. Learners learn to organize understandings of their ideas in terms of verbal and non-verbal descriptions, analogies, diagrams, tentative models and other explanatory models and arguments relevant to support their explanation. Second strand requires the teacher to provide learners with resources, experiences relevant to answering essential questions, including but not limited to pressing them to compare and integrate ideas across different knowledge resources and experiences as well as cultivating evidence on different sides of issues. Thus learners learn complex concepts, participate in authentic scientific practices, collect evidence, solve problems individually and with others as a team, and make inferences about the natural world of science.

The third strand requires the teacher to craft discursive strategies that can help learners generate several ideas –state testable hypotheses, construct new knowledge and ideas, show how they fit together based on their own critical insights, advance arguments based on models, theories, experiments, data, observations, solve problems, make inferences and address alternative hypotheses in a scientific way so as to arrive at a reasonable solution (Figure 3). Learners learn to construct a 'big picture' perspective of science, develop reasons about how the different ideas of a model, theory, law interact. Learners learn to make predictions, and investigate by asking 'what would happen if…', collect and tabulate data, provide instances when recorded data are misleading, analyse economically and meaningfully in the language of mathematicians and scientists, so they measure, draw graphs, and communicate useful information. The fourth strand expects the teacher to provide learning opportunities that increase learners' active participation and construction of ideas as they work in a scientific way. Learners adopt community of practice approach to learning, learn to collaborate, gather relevant information, test models, learn new concepts needed to understand a given problem, solve problems, evaluate solutions to problems or explanatory models, and propose an evidence-based solution (Figure 3). However, what the four strands look and sound like in practice has not been well-translated into instructional practices of science teachers in many countries (Furlong and Davids, 2012; UNESCO and UNICEF, 2013a). This is another gap that must be bridged. Accordingly we need instructional approach that allows learning through authentic real-world contexts, carrying out projects from beginning to end, and solving problems as they arise.

Bearing in mind Figure 1, it is surely reasonable to argue that pedagogical practice that hopes to attract the attention of this age-group learners in science must include diverse skills of media-technology into what is to be learned (see Figure 4). On this point, learners would need to work with others (classmates, teachers, other schools, countries), on projects utilizing wikis, blogs, discussion boards, Google docs, Skype, etc) (McKnight et al., 2016). Both technical and digital navigation skills as shown in Figure 4 will form part of science didactics now and in the future. According to Grand-Clement (2017) digital skills are technical skills required to use digital technologies, whereas digital navigation skills are a wider set of skills needed to succeed in the digital world.

Figure 4. Necessary skills for digital age learning in science now and in the future
Image: Adapted from Grand-Clement (2017, p.5)

From the foregoing it would appear that the position of the science teachers/instructors is more fluid and less clear cut. On the other hand, concepts and methods are both explained by means of language. This is self-evident to suggest it is language that carries the whole pedagogic practice and gives the learner the means to keep the result of learning and the knowledge acquired in its abstract form. It appears, therefore, that language of instruction can be a barrier in learning science – especially for those who receive science instruction in English but for whom English is their second or third language (Echevarria et al. 2011; Wilson, Copeland-Solas, and Guthrie- Dixon, 2016). The question which has not been asked is how to integrate language and science content effectively for learning in digital and social age. Information is available about some of the learning models in use with this age-group in science. The clearest example is the researches of Short, Vogt and Echevarria (2011), Short (2017), Wilson et al. (2016) which have examined the effect of language on the learning of science using the Sheltered Instruction Observation Protocol (SIOP) model. Results from their studies have clearly indicated that science leaners engage with the subject area topics in a comprehensible manner than their counterpart with teachers who were not trained in the SIOP model. Further to this result, it must be recognized, of course, that creating an enabling environment in which such model gets implemented effectively can take many forms. This argument is particularly persuasive if one considers Figures 2 and 5, respectively.

The issues raised in the preceding sections, together with those that follow, envisage the need for pedagogical innovation which aims at equipping today's learners with scientific knowledge, skills and competences to function in a rapidly changing world. Certainly, radical changes in science teaching and in science teacher education programmes will be essential. The implication that can be drawn from the researches of Franklin (2015), Mynbayeva et al. (2018), Slough and Chamblee (2017) and others is that the twenty-first century science pedagogy requires teachers to rethink their reasoning about what they teach, what learners learn and why, and to rethink about the driving change in the ways that learners are taught (UNESCO and UNICEF, 2013a). But as is known, science teachers in many countries still find it difficult to manage their teaching and learning at the speed of life world, and as a result they continue to deliver their teaching through transmission model (Mynbayeva et al., 2018; Twum, 2017; UNESCO, 2012).

CHANGES THAT HAVE NOT CHANGED SINCE SCIENCE LEARNING

A significant problem confronting the development of the 21st century skills and competences among science learners is mainly teachers' reluctant or resistance to move away from traditional method of teaching (Karakas, Manisaligil, and Sarigollu, 2015; Voogt, Erstad, Dede, and Mishra, 2013). The traditional method of teaching still prevails as the dominant instructional approach in education throughout much of the world (Saavedra and Opfer, 2012; UNESCO, 2012). Roth and Garnier (2007), in a significant review of the nature of classroom discourse shows that in American classrooms "almost one-third of the lessons narrowly focused learners' attention on performing activities with no attempt on the teachers' part to relate these activities to science ideas" (p.20). The standard school 'transmission model' can make any subject matter seem irrelevant, and in addition undermines the possibility of developing skills because lack of relevance leads to lack of motivation, which ultimately results in decreased levels of learning (Saavedra and Opfer, 2012, p.9). When science is taught in this way, it defeats the purpose of scientific thinking, and ignores the tremendous subtlety, variability, and context dependence in learners' thinking and reasoning, and the important domain-specific knowledge they bring to school, especially knowledge of the natural world (NRC, 2007). At the extreme, transmission model does not produce the twenty-first century scientifically literate youths we need so badly, nor does it attract bright innovative minds to further studies in science (Mynbayeva and Sadvakasova, 2007). This is a gap that must be bridged.

Serious questions are now being raised about the way the 21st century curricula activities are taught in schools (UNESCO, 2012). These include the concern over learning activities that are designed to connect learner experiences to real-world problems and teachers' status quo to surmount learners' declining interests in learning science through their current pedagogical practices (McComas, 2017). The dissatisfaction that some learners feel for science can be explained by teachers' lack of ability to create active learning opportunities that is relevant to learners' life world. The Partnership for 21st Century skills (P21, 2007b) echoes this point: 'when learners realize the connection between what they are learning and real-world issues that matter to them are not in agreement, their motivation soars, and so does their learning' (p.3). The increasing likelihood of science classroom becoming irrelevant to interests and issues that affect learners is therefore of real concern (ICSU, 2011; NRC, 2012). As some researchers have noted, bridging this gap will require more than superficial attempts to combine education and the use of the latest technological devices (Franklin, 2015; Mynbayeva et al., 2018; Slough and Chamblee, 2017). Results that support this suggestion were obtained by UNESCO (2012), suggesting that the quest for new knowledge paradigm through mobile learning could help to offer learning opportunities for all learners as depicted in **Figure 1**.

TEACHING SCIENCE AND MAKING IT RELEVANT FOR THE 21ST CENTURY LEARNERS

Growing calls for science pedagogical innovation reflect the view that 21st century learning will become a process of knowledge creation managed through personalized modes of learning and individualized teacher support (Aslan, 2015; Karakas et al., 2015; Slough and Chamblee, 2017). To achieve this, science activities must be relevant to the lives of learners with focus on the knowledge resources, strategies and contexts that learners will encounter in real-life after graduation (King and Kitchener, 2004). Certainly, a transition is necessary in which learners learn to participate in science activities that demand deeper engagement on their part. This transition is a process that is dependent on teachers' acceptance of what is expected of them to replace outmoded classroom models of teaching and learning science with learner-centric models (McComas, 2017; Moemeke, 2014; Voogt et al., 2013), including the use of mind map (McCrea & Lorenzet, 2018). In terms of pedagogical practice, many salient researches have provided useful insights about how mind mapping can be used in diverse fields to make teaching and learning more stimulating, enjoying and effective in science (Wilson et al., 2016), health science (Rosciano, 2015), engineering (Dixon and Lammi, 2014), and education research methods (Murtonen, 2015).

Mind map has been used to foster development of concepts, construction of knowledge, and thinking pattern that supports learning in digital age. In the simplest sense, mind map can be loosely defined as a visual tool that is used to organize information with focus on comprehension, analysis, synthesis, generalization, evaluation, decision-making, problem-solving and creative thinking, all of which present a corpus of knowledge to be constructed and mastered by the learner (Mohidin, 2011; Wilson et al., 2016) (**Figure 5**). At best, it has led to several technology-based developments in teaching and has become an increasingly important element that can be used to develop stronger or new mental processes for deeper learning, understanding of concepts and ideas as well as a possible approach to teaching science learners how to learn. Tailoring science teaching and learning pathways to the characteristics and aspirations of individual learners will undoubtedly demand critical changes, including a greater emphasis on learners taking responsibility for their own learning and development (Carneiro and Draxler, 2008; Facer, 2012).

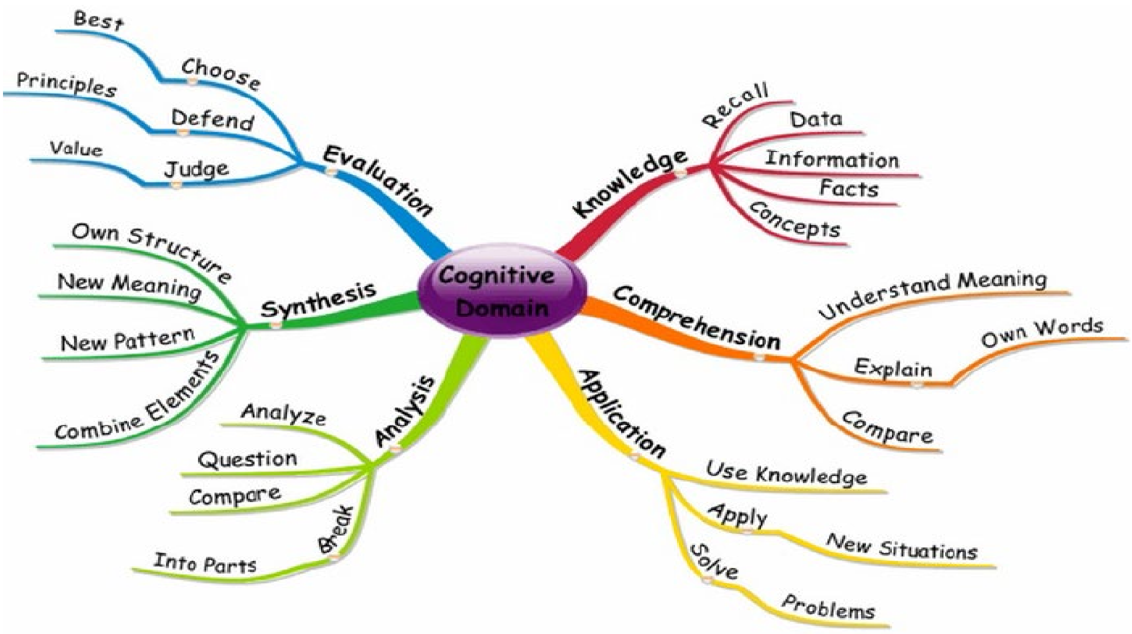

Figure 5. Adapted from Mohidin (2011), Using Mind Maps

An atmosphere must be developed in which learners feel free to offer a viewpoint and in which it is acceptable to make mistakes and correct them. Using learners' viewpoints as much as possible and not impatiently imposing a viewpoint on them could be useful way of managing new forms of classroom dynamics and the gaining of new understandings and skills to prepare them for today's life world (Trilling and Fadel, 2009). When science teaching becomes relevant to learners and advocates their methods of thinking, learning, and solving problems, it encourages active participation, and increases cognitive or perceptive shifts among them (Price and Hill, 2004). Also, the meaningful use of information and communications technology (ICT) and new technological devices in both formal and informal settings may also increase opportunities for learner-driven forms of learning science (Moemeke, 2014; Mynbayeva et al., 2018). Therefore, designing relevant and real-world investigative activities and aids can play a vital role in affording learners the opportunity to engage in meaningful science learning (Lederman and Lederman, 2014). This places additional emphasis on promoting teaching and learning science without borders through ICT. In this sense, science teachers must become comfortable with managing new forms of learning and the emergence of learning spaces beyond classrooms and schools.

In this 'digital age', science learners can learn anytime and anywhere and will continue to seek and acquire knowledge wherever and whenever they need it from variety of sources including, digital books, websites, informal learning, social media and experts around their world life. Such move will require science teachers to adapt to these extreme changes and will also demand their readiness to support their learners when the need arise. Results that support this suggestion were obtained by Adams and Gupta (2017) who described how working in informal settings and learning to use the affordances of that setting supports aspiring teachers to connect theory to practice that is learner-centered, responsive to the needs of learners, and allows for the imagination of future selves and classrooms that are conducive to maintaining diverse learners. Figure 1 illustrates this point well in that learning anywhere and anytime can help the digital and social age learners to develop the ability and skills ready to be applied in a variety of contexts in science. Fostering this commitment will ensure that learners remain open to new science developments and opportunities as they arise. This trend has the potential to transform the ways in which today's science learners contend with scientific complex problems that affect them, their communities and societies. Unfortunately, researches have shown that there is a gradual move away by schools and teachers from traditional classroom-based learning towards anyplace, anytime and open education (Gijsbers and van Schoonhoven, 2012). This is a gap that must be bridged.

BRIDGING THE GAP BETWEEN WHAT WE TEACH IN SCIENCE, AND WHAT LEARNERS LEARN

The strategies employed to enhance science relevancy and to make it more understandable to learners are, according to Bell, Matkins, and Gansneder (2011), Moemeke (2014), Slough and Chamblee (2017), part of an overarching goal. That is, teaching content alone is not likely to lead to 'proficiency in science', nor is engaging in 'inquiry experiences' devoid of meaningful science content (NRC, 2007: 335). Just giving learners activities to perform or discuss will not prove sufficient to ensure scientific practice which needs to be fostered by science teachers. Thus, learners need to participate over time in explicit discussions in the norms and criteria that underlie scientific work (Hogan and Maglienti, 2001). For today's science learners, real-world experience should permeate learning activities. On the teachers' part this is accomplished by employing a range of problem-based learning activities that require peer collaboration: focusing on individual creativity and performance, meta-learning, and practical work - including strategies for creative modes of reasoning (Saavedra and Opfer, 2012).

The active use of innovative science teaching methods by teachers is a necessity for today's learners. Science teachers should be able to manage teaching and learning at the speed of learners' life world by constantly improving their didactic skills, selecting and developing new methods and technologies for teaching (Mynbayeva et al., 2018). Utilization of experiential learning, storytelling, enquiring learning, appropriate assessment, future problem solving, outside classroom learning, and community problem solving are some of the essential teaching strategies recommended by the UNESCO (2012). As part of embracing the future of today's learners, the use of innovative teaching methods and constant search for new ways on how to better learners' understanding of science is necessary. Beyond general agreement by some scholars about finding new ways to teach science, the manner and degree to which NOS instruction is contextualized varies (Bell et al., 2011). Thus, research is needed that addresses teachers' NOS instruction and learner outcomes in the arena of science. Yet, the level of guidance may matter for which teachers' instruction and experiences are examined through time, in accordance with Lederman and Lederman's (2014) recommendation to move beyond the idea that pedagogical innovation will produce new forms of learning and new competencies (Redecker and Punie, 2010; Saavedra and Opfer, 2012). And that's where the gap gets filled.

It may seem surprising that nearly two decades since the dawn of the 21st century, and with the increasing environmental, health, social, political and economic challenges the world is facing, no curriculum innovation has satisfactorily met the needs of today's learners (Carneiro and Draxler, 2008; ICSU, 2011; UNESCO-ERF, 2013). We need to be critical in what we teach in science and what our learners learn. If teachers ever cease to be critical of what they are teaching in science, then what their learners are learning will become fruitless. If today's science teachers are to meet the needs of twenty-first century learners, they must not only develop what they know, but also how they know (ICSU, 2011). In an age of increasing numbers of identified science learners with little or no interest in what they learn in science, science teachers need to be prepared to rekindle learners' interest as they learn about and engage in science. Science learners should benefit from the science education provides, which includes understanding the nature of science, scientific dimension of phenomena and events of natural world, role of science in society, adaptability, appreciation of the potentialities and limitations of science, and its contribution to citizenship (NRC, 2007, 2012). Change must take place not just inside science classrooms, schools and central management, but also outside – in the culture, systems, policies and structures that shape and support what happens in the science classroom (Franklin, 2015; ICSU, 2011; UNESCO and UNICEF, 2013a; Zeidler and Abd-El Khalick, 2017). In moving toward such change, whilst every nation has its own vision of what a twenty-first century science education should look like, all countries will face consequences if today's science learners are not adequately prepared to collaborate and resolve the ever-expanding global, diverse, and technical economy challenges.

Finally, the roles of science teachers in teaching today's learners should be extended as mentors, mediators, facilitators, learning coordinators, assessors, and designers and compilers of learning tools. Every science teacher should consider it important that he prepares today's science learners to fill his country's need for scientists and technologies. Science teachers will have to avoid stuffing today's learners with facts for the purpose of collecting paper qualifications, since this sort of dead activity stifles imagination, resourcefulness and creativity, qualities vital to a country's science and technology. Since there is no perfect way of teaching science, this paper suggests that science teachers must constantly seek to bridge the gap between their current instructional practices and the changes that are taking place related to innovation in teaching and learning. They must read as broadly and as deeply as possible so as to manage teaching and learning at the speed of life world. It is then hoped that this paper can serve as a basic document with which to begin.

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