Exploring the use of Artificial Intelligent Systems in STEM Classrooms

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Abstract

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Human beings by nature have a predisposition towards learning and the exploration of the natural world. We are intrinsically intellectual and social beings knitted with adaptive cognitive architectures. As Foot (2014) succinctly sums it up: “humans act collectively, learn by doing, and communicate in and via their actions” and they “… make, employ, and adapt tools of all kinds to learn and communicate” and “community is central to the process of making and interpreting meaning—and thus to all forms of learning, communicating, and acting” (p.3). Education remains pivotal in the transmission of social values including language, knowledge, science, technology, and an avalanche of others. Indeed, Science, Technology, Engineering, and Mathematics (STEM) have been significant to the advancement of social cultures transcending every epoch to contemporary times. As Jasanoff (2004) poignantly observed, “the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it. […] Scientific knowledge [..] both embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments, and institutions” (p.2-3). In essence, science remains both a tacit and an explicit cultural activity through which human beings explore their own world, discover nature, create knowledge and technology towards their progress and existence. This has been possible through the interaction and applications of artifacts, tools, and technologies within the purviews of their environments. The applications of technologies are found across almost every luster of organizational learning especially teacher education, STEM, architecture, manufacturing, and a flurry of others. Thus, human evolution and development are

inexplicably linked with education either formally or informally. The 21st century has however seen a surge in the use of artificial intelligence (AI) and digital technologies in education. The proliferation of artificial intelligence and associated technologies are creating new overtures of digital multiculturalism with distinct worldviews of significance to education. For example, learners are demonstrating digital literacy skills and are knowledgeable about AI technologies across every specter of their lives (Bennett et al., 2008). It is also opening new artesian well-springs of educational opportunities and pedagogical applications. This includes mapping new methodological pathways, content creation and curriculum design, career preparations and indeed a seemingly new paradigm shift in teaching STEM.

There is growing scholarly evidence about the use and diffusion of these technologies in K-12 and higher education (Bonk & Graham, 2012; Hew & Brush, 2007; Langer, 2018; Mishra & Koehler, 2006). Some of these include the *Sphero robots*, Micro Bit, Jill Watson, *BrickPi3 Classroom kit, Engino STEM Mechanic, Lego Education WeDo Core Set* and Spike. Both educators and learners are using these in STEM programs as well as other education related activities. Just as human activities and interactions with artifacts and tools shaped and redefined the scientific-technological feat of previous generations, so the contemporary digital technological era seems to be on a similar trajectory. However, there is sparsity of empirical scholarship on the pedagogical prospects and effectiveness of artificial intelligence in STEM classrooms. Also, it should be noted that scholarship on how AI impacts pedagogical content knowledge of STEM educators and how learners perceive these technologies are just emerging. In addition, the recent COVID-19 pandemic (Ghandhi et al., 2020; Rasmussen et al., 2020) has unexpectedly created a renewed synergy towards the applications of digital technologies in teaching STEM. In the context of this *force majeure* (COVID-19), the traditional brick and mortar educational spaces metamorphosed into digital spaces with the applications of many artificial intelligent technologies and resources in the arena of education. This doctoral dissertation study examined these enigmas including how educators use these technologies in STEM classrooms. The study is informed by *activity theory* or *cultural-historical activity theory* (Engeström et al., 2007; Hasan et al., 2014; Krinski & Barker, 2009; Oers, 2010; Vygotsky,1987). The study participants will be selected from educators currently integrating artificial intelligent systems and digital technologies in their respective STEM classrooms. Pre-data survey inquiry has shown that many educators were incorporating some forms of AIS into their STEM classrooms.

In view of these, I have explored Sphero educational robots to interrogate the research topic. The Sphero Edu described as a "…*STEAM-based toolset that weaves hardware, software, and community engagement to promote 21st century skills. While these skills are absolutely crucial, our edu program goes beyond code by nurturing students' creativity and ingenuity like no other education program can"* (Sphero, April 2020). The Sphero robots also have features and applications for designing and teaching STEM topics such as nature, space science, geometry, and other activities of pedagogical significance. Users could also design and write advanced engineering programs in JavaScript during STEM educational activities formally and outside of the classrooms. In essence, educators and students can learn designing, programming, engineering, mathematics, computational thinking, and hands-on skills reflective of the 21st century.

In brief, the dissertation study research has explored artificial intelligence and emerging technologies and how these could transform and advance teaching and learning of STEM hence the research topic: *Exploring the use of Artificial Intelligent Systems in STEM Classrooms.* Methodologically, this is a qualitative study through the theoretical frameworks of *activity theory* as applicable to STEM education. The main research questions are:

1) *Given that artificial intelligent systems* and *digital technologies* have been applied in STEM educational domains (content, pedagogy, student learning, assessment). How does the application of AIS and digital technologies impact pedagogy *in STEM educational activities*?
2) Given that digital technology is transforming contemporary society in every facet. How/What does AIS tell us about how digital technology impacts STEM pedagogy?

Data was collected from the study participants, archival sources, and others for analyses. It is hoped that the findings will inform and address theories of learning and teaching, policy and praxis in science education, teacher preparatory and professional development programs as it relates to STEM classrooms.

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Acknowledgments

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Finally, I wish to express my profound thanks to my family abroad and in the United States America for their support and encouragement throughout my program of study towards the doctorate. To my son, I am infinitely grateful for your kindness and curiosity about my research. Your consistent question: "*how is your research coming along*?" often punctuated by your occasional requests to take you to the playground during the most demanding parts of the dissertation, gave me cause to refresh and motivated.

Dedication

I dedicate this to my parents (in memoriam) and family for their unwavering love and support throughout my life and academic pursuits. Though my parents did not live to see this monumental accomplishment of my doctoral studies, nonetheless their footprints of love, honesty, respect of everyone and their respective cultures, and dedication to academic scholarship has sustained me throughout my studies.

In addition, I dedicate this to Rita Hofbauer who has demonstrated her unalloyed support for my cause especially academic and professional excellence since I came to the United States of America.

I dedicate this to all who pursue equal and equitable access to quality education.

Introduction

The innovation and proliferation of artificial intelligence and associated technologies are creating new frontiers of digital culture and worldviews in society (Bennett et al., 2008; Bonk & Graham, 2012; Buckingham, 2006; Rhoads, 2015; Sitzmann et al., 2006) with significance for STEM education. There is a concurrent synergy of a new paradigm shift towards STEM education especially at the K-12 educational sector in the USA. The disciplines and practice of Science, Technology, Engineering, and Mathematics (STEM) and allied intellectual pursuits drives human progress and development (Snow et al., 2017). STEM and the arts promote and bolsters cross-curricula, interdisciplinarity and the integration of the arts and sciences into contemporary scientific pursuits (Dennick & Sutherland, 2002; Emdin, 2013; Ming, 2012). It also promotes divergent thinking (Hunter-Doniger et al., 2016; Sousa & Pilecki, 2013) where students bring diverse skills and concepts from the arts and integrate them into the sciences to understand a natural phenomenon or a problem and offer or create diverse solutions or products. These are consistent with the vision of core standards and the *Next Generation of Science Standards* (NGSS) marking a paradigm shift (Kuhn, 2012) in science education policies and practices in the United States (Bodrova, 2006; Ming, 2002). It is anticipated that digital culture will impact the teaching and learning of STEM. Some scholars (Brynjolfsson et al., 2011; Palfrey et al., 2013; Zanzotto, 2019) have speculated that artificial intelligence will drastically reduce the human component of productivity and therefore change the trajectory of education (including STEM) in the world. It is a truism that modern learners are digitally literate and skilled (Palfrey & Gasser, 2013; Riley, 2012; Shashkevich, 2019) with AI technologies across every sphere of their lives. This phenomenon is apparently disrupting organizational structures and practices (Bonks, 2009 & 2015; Brynjolfsson & McAfee, 2014; Holbert, 2002; Korneru, 2010; Langer, 2018; Masie, 2005; McCulloch, 2018) including the field of education and pedagogical practices (Gauch, 2009; Good, 2002; Jackson et al.,2006; Palfrey et al., 2013). Some scholars (Arafeh & Levine, 2002; Bennet et al.,2008; Buckingham, 2006; Palfrey & Glaser, 2013; Prensky, 2001) have described current or students born after the 1990s as digital natives due to the concurrent emergence of digital technologies. Others before the 1990s are perceived as digital aliens or digital immigrants. Some educational institutions are embracing these novel technologies as a *sine qua non* for the twenty first century world (Bonk & Graham, 2012; Langer, 2018). The research reported here focuses on artificial intelligent systems and digital technology and associated culture (worldviews) ostensibly to understand what these technological *tools* and *artifacts* mean to each segment of research participants (STEM teachers/educators). For example, how do participants' experience of AI impact STEM *educational activity systems* and pedagogical practices?

Currently, AI tools under the taxonomy of "intelligent tutoring systems" such as Jill Watson, AutoMentor, iSTART, iDrive, Operation ARIES, DeepTutor are increasingly used by some educators, students and educational institutions to augment their STEM classes covering many topics (Hu et al., 2012; Johnson et al., 2015; Kopp et al., 2015; Rowe et al., 2010; Olney et al., 2012; Ward et al., 2013; Wolfe et al., 2015; Zapata-Rivera et al., 2015). *Sphero Educ Robots*, an AI tool with many subcategories are currently in use in teaching both STEM and languages in some schools in the country. Indeed, some institutions have been using Sphero Educ Robots and other programs to teach STEM topics such as patterns, geometry, biologic systems, data and graphics, designs, coding, and others. Teachers and learners proficient in the foundational knowledge and skills of AI language and dynamics can write endless codes, design many products, undertake mathematical and engineering projects of significance. As Brynjolfsson & McAfee (2014) correctly characterized AI technologies as *combinatorial* and *generative* and the current applications of Micro Bit, LEGOS, and Sphero Educ Robots in STEM education among others seem to affirm these descriptions.

However, there is limited scholarly data about these technologies and their actual impacts on teaching and learning of STEM. Hence my research analyzed and studied the prospects and impacts of AI technologies in teaching and learning of STEM in the 21st century (Buckingham, 2006; Combi, 2016; Fogarty et al., 2011; Graesser, 2016; Hu et al., 2012; Olney et al., 2012; Palfrey et al., 2013; Rowe et al., 2010) therein in a digital world. This is a qualitative research (Biklen & Casella, 2007; Creswell et al., 2018; Saldana, 2011; Taylor et al., 2016) and I have partly examined digital culture and associated technologies. As I have indicated above, there are many AIS and digital technologies in use in STEM classrooms. I have focused on Sphero robots as an exemplar of AIS. Research participants were teachers/educators currently using AIS such as the Sphero Education Robots in their STEM educational programs or activities.

In brief, the study explores the application of AIS and digital technologies cognizant of digital culture in STEM classrooms at the K-12 levels. Consideration was accorded subjects who used these technologies and /or have some experiences of these in their respective school culture or STEM classrooms in view of the research topic:

Exploring the use of Artificial Intelligent Systems in STEM classrooms.

Purpose of the Study

The advent of artificial intelligent systems (AIS) and digital technologies have created a digital worldview and concomitant culture of pedagogical significance. Teachers are using AIS to generate lesson notes, develop novel methods and scaffold teaching, among others. Indeed, contemporary classrooms are being transformed with the introduction of diverse AIS to advance STEM lessons, assessments, note taking, research and many other pedagogical domains. As noted at the beginning of this chapter, there are many types of AIS in use in STEM classrooms at the K-12 levels. However, there is sparsity of empirical evidence to buttress the hypothesis that these AIS are pedagogically efficacious especially in STEM classrooms. Accordingly, the study explored the use of AIS and its significance and impact on teaching of STEM in the 21st century. The study focused on the use of Sphero educational robots and applications in STEM classrooms. Sphero educational applications and robots are among one of the popular AIS technologies currently being used by teachers at many K-12 STEM classrooms. It has many features of educational significance in the domains of content generation, pedagogy, assessment, and administration as particularly applicable to students, educators, and administrators. However, the research focused on educators currently using the Sphero educational robot and applications in their respective STEM classrooms. Hence the dissertation study participants are certified Sphero Educators. One of the goals of the study was to collect primary data on the use of AIS in STEM classrooms. I believe this data will elucidate the prospects and challenges coterminous with the use of AIS educational apps in STEM classrooms at the K-12 levels.

Additionally, there is an assertion that AIS is transforming STEM classrooms including pedagogical practices and learning (Lester et al., 2010; Rhoads, 2015; Riley, 2012). This was reiterated during the literature review and pre-data collection phases of this dissertation study. In view of this, the study critically delved into this hypothesis to determine if there was any empirical evidence to substantiate this assertion or vice versa. The research also examined the prospects of teaching STEM in contemporary times with AIS and digital technologies as computational thinking skills have become an emerging concept in both academia and industry amid the proliferation of AIS and digital technologies. How does AIS (herein Sphero educational applications and robots) promote or advance this skill? Responses to these and others have been examined through the theoretical framework of *activity theory* (Engeström, 2018; Engeström et al., 2007; Foot, 2014; Munipov & Zinchenko, 1979; Mwanza, 2001; Nardi et al., 2016; Plakitsi, 2013; Ritva Engeström, 2014; Vygotsky, 1978). It is anticipated that the empirical data and findings from this doctoral dissertation study contribute to the scholarship at the intersection of AIS and STEM and teacher education at the K-12 levels.

Chapter 1: Literature Review

1:1 Introductory Comments

In the *Allegory of the Cave* which appeared in *The Republic*, Plato offers a fascinating dialogue between Glaucon and Socrates, which has since become a hodgepodge for epistemological and educational discourses (Heidegger,1998; Losin, 1996; Moline,1981; Reeve, 1988; Vlastos,1973). Plato asks the reader to imagine a group of people trapped in a dark subterranean cave facing the walls all their lives. A fire is presumably burning behind these trapped folks and as a result shadows of objects/statues and their own are projected onto the hitherto blank walls before them. For these folks, their *worldviews* and understanding of reality is confined and defined by their experiences in the cave and the shadows cast in front of them and not the actual objects as they occur in nature. Plato suggested that as these folks eventually extricate themselves out of the cave and see the Sun for the first time, they will be blinded momentarily by the intensity and power of the luminosity of the Sun. However, upon gaining some modicum of clarity they begin to discover the contrasts between what they thought was reality while trapped in the cave and their actual experience of objects as they see and encounter them and the 'ideas' or concepts of these in their imagination. Cusped in epistemological gerunds, their conceptual perspectives and framework undergoes an axiomatic paradigm shift as they can now experience and see things in a different light. For example, instead of a shadow statue of a dog, they can see a real dog and can conceptualize these realities. They can further abstract the concepts and ideas of these objects in concrete and experiential terms. Indeed, their experiences and emergent *worldviews* have profoundly impacted their perceptions and knowledge of the world. The notion of reality or certainty of knowledge seem innate and emanates from the individual. As Descartes indicated, *I am certain that I can have no knowledge of what is outside me except by means of the ideas I have* *within me.* Hence, the human capacity for knowing (episteme) is contingent on an individual's worldviews or perceptions. Ideas, perception of reality and the innate capacity to think and reflect on them are definitive matrices for the formation and development of an individual's epistemological ecologies and therefore their respective worldviews. Our world today is increasingly driven by many forms of artificial intelligence (AI) and associated digital technologies (Langer, 2018; Palfrey et al., 2013; Prensky, 2013; Wellman et al., 2008). Some of these are found in basic computational and mobile devices, autonomous machines, automated robotics in biomedical research and medicine, deep machine learning and smart boards. Some AIs are also exclusively designed for STEM classroom settings. For example, in the case of *Jill Watson.* To augment his teaching staff, Prof Goel developed Jill Watson to serve as a teaching assistant. Jill worked throughout the day and night answering students' questions, guiding them through their coursework and others as many teaching assistants ordinarily do. Jill purportedly endeared her students earning many accolades and excellent reviews at the end of the semester. Unbeknownst to the students, Jill Watson was a robot- an artificial intelligent system!

Undoubtedly, the emergence of AI is shaping our contemporary worldviews and perceptions of reality potentially edging the field of science education into a different level. Akin to the *Allegory of the Cave* described above, AI and associated technologies have created a new epistemological frontier and an emerging worldview (albeit a digital culture) for science education-teaching with skills needed and associated in the 21st century (Bennet et al., 2008; Bonk et al., 2012; Glenn, 1989; Langer, 2018) worldviews (Irzik et al., 2009). This new frontier, cusped in Heideggerian(1998/1967a) terms means "...the turning around of the whole human being in the sense of displacing them out of the region of immediate encountering and accustoming them to another realm in which beings appear" (p. 254) and "genuine education leads us back to ourselves, to the place we are, teaches us to dwell there and transforms us in the process" (p. 254). AI seems to be on the threshold of extrapolating education from the precipitates of industrial revolutionary educational models to new educational experiences under the aegis of digital worldview and associated digital cultural technologies (Barrett et al., 2012; Bennett et al.,2008; Bonk & Graham, 2012; Daniels, 2001; Forgarty et al., 2011; Jackson & Grasser, 2006; Madden et al., 2013; Moore, 2018; Panesar et al., 2019).

In this chapter, I have discussed concepts and terms such as artificial intelligence, digital technologies, and digital culture. I believe an understanding of these key concepts will unveil the key to unlocking the Pandora box of the dissertation research topic. To that extent, I have briefly expatiated on these terms and proposed some operational definitions given the wide scope and usage in current scholarship. I have also analyzed the technology undergirding AI and digital applications and explored how it continues to create and shape current demographic worldviews and examined the potential implications for STEM education with a focus on the Sphero Educational Robots and applications.

Digital Culture and STEM Education

1:2 An Exposé on Artificial Intelligence and Digital Technology

The term artificial intelligence (AI) has become one of the center pieces in the halls of academia (Crowder et al., 2013; Langer 2018; Panesar et al., 2019), international conferences (Boyer & Moore, 1997; Crowder & Carbone, 2011) on socio-development policies (Mühleisen, 2018), financial sectors, entrepreneurs (Press, 2017; Porter & Heppelmann,2014; Nambisan 2016) just to mention a few (Mayor, 2019). Research output and citational indexes (Jiqiang et al., 2016) continue to aggregate to unprecedented levels on the nature and meaning of the term, artificial intelligence, digital technology, and digital culture (Bloomberg,2018; Buckingham, 2006; Crowder et al., 2011; Masie, 2005; Mayor, 2018; Popenici & Kerr,2017). These factors as well as the infusion of substantial capital for research and development (R&D) on AI elicits interests across every specter of society. These naturally interest educational organizations and other sectors (Bonks, 2013; Langer, 2019) privy about the direct and indirect impacts of AI. But the term AI is broad and encapsulates others such as, Cognitive Intelligence (CI), Machine Learning (ML), Deep Learning (DL) and Digital Technology (DT) (Panesar et al., 2019). According to Panesar et al. (2019) AI is "…the simulation of intelligent behavior in agents (computers) in a manner that we, as humans, would consider to be smart or human-like. The core concepts of AI include agents developing traits including knowledge, reasoning, problem-solving, perception, learning, planning, and the ability to manipulate and move" (p.4). This initial definition aligns AI as exhibiting traits like human beings. For example, AI can reason, learn, and even plan, although these are normally ascribed to higher intellectual faculties of human beings. This is one of the reasons for the emergence of another close term and concept *Machine Learning* (ML). Arthur (1959) of IBM is reputed to have coined the term *machine learning* on the premise that computers can learn if taught. For instance, they could be calibrated with algorithms and trained to learn and sometimes solve conundrums not initially associated with their functions. And as Panesar et al. (2019) noted, "machine learning can be understood as an application of AI" and "deep learning utilizes deep neural network architectures, which are types of machine learning algorithms" (p.90). These initial definitions and analyses seem to give credence to the concept of artificial intelligence which has existed and transcended human existence over a millennium (Mayor, 2019); while digital technology as a term emerged beginning in the 1950s replacing analog data technologies.

Thus, digital technology has become coterminous with the advancement of artificial intelligence due to the apparent relationship between the two terms. Digital technology includes artifacts, platforms and infrastructures upon which AI operates. Digital technology remains a narrower concept and represents tools on which AI are applied and used in different and unique forms at various applicable levels and socio-cultural contexts. This has led to the emergence and application of the rather broader term *artificial intelligent systems* which encapsulates AI as defined above and digital technologies reliant on AI artifacts, platforms, and architecture to stimulate human intelligence, judgment, predictions, and others.

In the proceeding paragraphs, I have presented an exposition on the term *Artificial Intelligence* as well as *Digital Technology*. I have examined some of the characteristics or traits of the terms to the extent that they are applicable to STEM education. Accordingly, when not defined, AI in this dissertation entails machine learning, and digital technology. I have also examined the word “intelligence” as in the term “artificial intelligence” followed by an exposition on the concept or term “artificial intelligence” in view of the research topic in a bid to develop a relevant operational definition.

1:3 What then is Artificial Intelligence?

One of the unique, but fascinating traits of human evolutionary trajectory, is *intelligence.* Contemporary scholars (Bennett et al., 2008; Bloomberg, 2018; Carbon et al.,2013; Clamp, 2001; Gardner, 1980; Howe,1991; Itzkoff,1987; Mayor, 2018; Palfrey & Gasser, 2013; Rus et al., 2013; Sagan et al., 1977; Sternberg,1990) have written extensively offering insights into the locus, and development, of human intelligence. Gardner (1980) proposed a novel perspective on theories of multiple intelligence in which he postulates that humans by nature live and function in many places. Accordingly, human beings exhibit traits of intelligence in accordance with the contexts and situations they find themselves. Sternberg (1985) propounded the *Triarchic Theory of Human Intelligence.* According to Sternberg’s theory, human beings have sets of intellectual abilities that they apply or use to achieve their respective goals in life or social contexts. Other scholars (Coles,

1997) hold the view for moral intelligence while Mayer and Salovey (1993) argue for emotional intelligence. There is no consensus per se on what constitutes human intelligence since there are various approaches and models of theories on the subject matter perhaps beyond the scope of this paper.

However, the association of the concept "intelligence" as in the term *artificial intelligence* requires further elucidation including the definition, etymological examination, and some operational understanding of the term. Intelligence has been defined by the Oxford Dictionary as, "…the ability to learn, understand and think in a logical way about things; the ability to do this well." Etymologically, "intelligence" is from the Latin word *intelligentia* or *intelligere*. And *intelligere* is a conjoined word- *inter* (between) and *legerre* (choose). Thus, *intelligence* from the etymological perspective is the ability to decide or choose between entities based on an understanding that is logically rooted about the entity from other options. Functionally, intelligence is a human quality that depends on many factors including autonomy, judgment, options, reflections, and the capacity to change and adapt to behaviors, among others. It also includes the human capacity to think, rethink, create and re-create, reflect, and re-reflect and the recognition of these processes with intent and ability to understand the natural world. This human trait, and penchant to adapt and innovate, has sustained generations. This is evident in linguistics development, science, engineering, technology, space explorations, medicine and allied sciences, and social organizations, among others. Indeed, human beings have an innate quest to explore the natural and the abstract world through the observation of phenomena including the scope of the scientific process with an array of methods and the help of machines and tools. As a reflection of their *intelligence*, humans have invented and continue to co-create complex machines with some defined capacities to perform many human-induced activities. Some of these include the abacus, the wheels and simple steam engines geared towards aggregating a better understanding of science as well as the improvement of their lives and societies. Despite these feats, none were deemed autonomously intelligent nor capable of self-thought or had the ability to make their own decisions except with a human operator or intervention. However, discoveries and innovations in human history especially in the twenty-first century have created novel technologies with capacities to exhibit human intelligence and perform some functions hitherto reserved for sentient beings. This leads us to the orbit of the notion of “artificial intelligence.” It is predicated “artificial” because these technologies are non-human, non-sentient entities exhibiting “intelligence” hitherto associated with human beings.

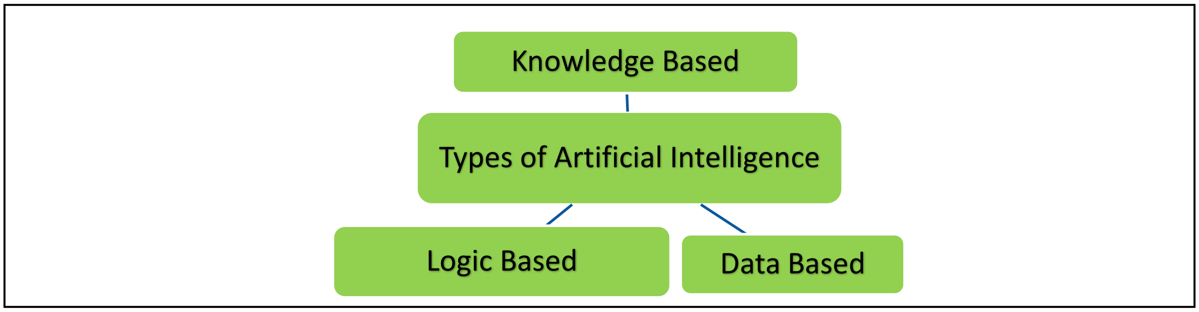
However, according to Press (2017), Turing’s pioneering works became a milestone for our contemporary scholarship on artificial intelligence. Indeed, Alan Turing earlier discussed the concept AI in his 1950 paper (Turing, *Computing Machinery and Intelligence*) and accurately predicted a future where machines such as computers will be “intelligent” based on some forms of “imitating game” as he calls it. Turing posited the formidable question: “Can machines think?” and extensively promulgated the thesis affirming the possibility (Rosli, 2005). It should be worth noting that in the 1950s, computers were a rarity in the public domain except in very few academic, research, government, and business enterprises. And most of these forms of AI were for computational, data storing and analytical purposes. Thus, the concept and term artificial intelligence remained sequestered in academia and industrial research. Despite these grey areas regarding the emergence of the term, there seems to be a consensus that McCathy formally applied the term and its derivative concepts to the lexicon of academia culminating in its formal adoption at the famous, *1956 Dartmouth Conference.* Even though the concept transcends many millennia and cultures (Mayor, 2019). McCathy et al. (2006) explicitly described the term artificial intelligence thus: "…the science and engineering of making intelligent machines" (p.29). Indeed, the preparatory document on the *1956 Dartmouth Conference* ipso facto states: "the study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it"(p.1). This broader definition of the term is significant given the context and forum in which it was used and discussed. AI was no longer a concept but an applied science of engineering intelligent machines to simulate human intelligence. McCathy and some of the pioneers of modern AI such as Alan Turing envisioned forms of machines capable of analyzing information and processing it and to a large extent make intelligent and autonomous decisions for any array of situations. There is no doubt that these pioneering concepts of AI are no longer footnotes of history but are real and tangible.

As Bock (1985) also noted AI "…is the ability of human-made machines (an automation) to emulate or simulate human methods for the deductive and inductive application of knowledge and reason" (p.180). This is a broader definition that includes clearly, the concepts of automation and the application of knowledge extrapolated from a machine imitating a human source (McCarthy et al., 2006; Minker, 2000, Russell & Norvig, 1995). However, a cursory look at many other components and functions suggests that even though this later definition of the term appears expansive, it does not include many other components and applications of AI in the broader sense of the concept. Indeed, some AI and embedded technologies are even capable of predicting human actions based on algorithms built in them that have undergone some form of adaptive learning and capable of making specific decisions not predicted during manufacturing. Described in a rather terse and verbose manner by the New York Times as "…the Embryo of computer designed to read, and grow wiser" (July 7, 1958), the Perceptron Mark I, analogized on neurobiology, is reputed to be one of the earliest known AI with a function to learn and differentiate geometric figures in the early 1960s. In the New York Times reportage of July 7, 1958, the Perceptron Mark I was described as an "…embryo of an electronic computer today that it expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence" (para. 2-3). This is consistent with Professor Rosenblatt (the inventor of Perceptron Mark I) who propounded the hypothesis that AI *could have an original idea* analogous to sentient beings. This undoubtedly laid the foundation for the complex field of neural network in AI and machine learning including deep learning (Panser et al., 2019). Even though the project was abandoned because of the lack of efficiency of the machines, nevertheless, the Perceptron Mark I was a *locus classicus*; a precursor to contemporary AI systems such as Jill Watson. That is technological tools under the aegis of AI.

Currently, AI exists in infinite forms and types. AI exists as robots in manufacturing, deep sea humanoid robots, virtual surgical components (CorPath System), deep space explorations (Kibo) and a concatenation of others. Smart boards, educational apps and virtual learning platforms may be deemed AI. These AI exhibit some forms of intelligence analogous to human intelligence and characteristics. Some scholars (Niewiadomski & Anderson, 2018) described these as "Strong artificial intelligence" (SAI) or "artificial general intelligence" (AGI). Due to the advent of different and unique forms of AI, scholars have made many attempts to classify them on the bases of functions, designs, applications, and many other characteristics. Indeed, some scholars (McCarthy et al., 2006; Russell & Norvig, 1995; Woodbridge & Jennings, 1995) have made many attempts to classify AI technologies currently in use across the world. A survey and analyses of current literature on AI suggests that three emerging classifications seem apparent (Mainzer, 1990) namely: logic-based, knowledge-based, and data-based AI.

Figure 1

Classification of Artificial Intelligence



Note: The classification of Artificial Intelligence is based on three systems: logic based, knowledge based, and data based.

The logic-based systems (Bacchus, 1990; Baral & Gelfond, 1994; Boyer & Moore, 1997; van Emden, 1982; Krzysztof et al.,1999; Wooldridge & Jennings, 1995) are programmed or coded with the capacity for logical and syllogistic reasoning including spatial representation of facts or objects. Minker (2000) describes logic-based AI as

> commonsense reasoning; knowledge representation; nonmonotonic reasoning; abductive and inductive reasoning, logic, probability and decision making; logic for causation and actions; planning and problem solving; logic, planning and high-level robotics; logic for agents and actions; theory of beliefs; logic and language; computational logic; system implementations; and logic applications to mechanical checking and data integration. (p.3)

This type of AI is permed with human neural networks and typically applied in the areas of linguistics analysis and learning as well as syllogism and mathematical predictions. The second classification of AI is knowledge-based (Engelmore, 1987; Howe, 1991; Rocca, 2012; Woodridge & Jennings, 1995). It is focused on specific domains of knowledge areas such as languages, finance, and business (Banks, Wall Street), avionics, manufacturing and heavy industrial constructions, medical diagnostics, learning and developmental diagnostics, among others. The third is data-based and appears to be the most popular applications and use of AI technologies. It relies typically on feeding the machines with lots of information herein “Big Data” for storing, processing, analyzing, and predicting (regressions modeling) among others. Examples of data-based AI include GraphLab (Low et al., 2014), R program, IBM SPSS, Qlik which are popular in academia for analyzing quantitative data and research in areas such as STEM, data science, psychology, neuroscience, and economics. R Program for example can analyze, model, and generate substantial output of varying statistical models and associated graphs and simulations on STEM topics and others. By simply uploading huge *data* for example census, population, sale, manufacturing records, STEM experiments, and flight data; a scientist can determine statistical values of significance in a relatively short time. For example, mean, median, p-values, regression such as logistic and probit regression values and other correlations and variations within a relatively short time, thus obliterating the huge resources and time hitherto required for such analyses. It can also be used to analyze STEM based assessments, students’ progression in school including other academic fields, perform behavioral patterns and others in STEM.

In brief, AI technologies have ushered in a new way of managing knowledge as well as affecting almost every specter of contemporary life. To some extent, human intelligence remains a driving force in learning and progress for many millennials. The renewed interests and diffusion of AI systems in a digital culture enthralls a new synergy of response in STEM education especially at the K-12 and teacher preparatory and licensures programs. While AI does not *ipso facto* imply digital technology, nevertheless the two terms have been used sometimes synonymously. I believe it will be prudent and useful to explicate the term “digital technology” in view of the trajectory of my dissertation research. I have therefore analyzed the term "technology" followed by the second term, *digital*. Juxtaposing the two terms (digital and technology), I have offered a brief dialectic meaning of the term and contextualize it for the purpose of my research as well as make the case for the preference of the broader term *artificial intelligent systems* as applicable to STEM education rather than *artificial intelligence*.

1:4 Digital Technology

Technology abounds in many types and in every culture and subculture (Engeström, 1987; Bridgman & Streeter 2000) and their respective activity systems. There are building, food, biomedical, agricultural, medical, aquatic, chemical, and other forms of technologies. Early humans' discovery of fire and clay is believed to have culminated in one of the earliest forms of technological feats as this led to the art of pottery, building, cooking, and manufacturing of many household tools (Archibugi & Iammarino, 2002; Bridgman & Streeter 2000; Inkster, 2012;). Egyptians for example mastered embalmment technologies over three millennials while Felkin (1884) observed the Kahura natives of Uganda performed a cesarean operation using local tools and technology and anesthetics (banana wine). This was captivatingly reported in a scientific piece entitled, "Notes on Labour in Central Africa" in the *Edinburgh Medical Journal*. In brief, technology is key to human existence, progress, security, and the quality of life and in every human activity system (Bloomberg, 2018; Bridgman, 2000; Engeström, 1987; Gauch, 1987; Glen, 1989; Jasanoff, 2007).

Additionally, technology as a concept often poses a definitional enigma to scholars even among erudite writers (Heidegger, 1977). Etymologically, the word, technology is related to the Greek term "techne" (art, craftsmanship, craft) translated into Latin as "ars" and transliterated into English as "art" as in contemporary English lexicon of "artful." According to Schatzberg (2018) *techne* is understood as "…the practice and knowledge of the arts both mechanical and fine" (p.16) until the nineteenth century when scholars "…reduced art in most usage to the narrower concept of fine art in effect, this shift in meaning, the narrowing of art to fine art, ended a millennia-old tradition of philosophical discourses about productive, knowledge and action" (p.16). The reduction of the concept technology seems to have been relegated to technical issues and knowledge such as craftsmanship, application of basic skills to practical problems. However, "technology can also refer to material artifacts, from prehistoric stone tools to nuclear power stations" (Schatzberg, p.2). This broad definition reflects changing trends in the usage and application of the term technology and by extension to digital innovations in contemporary times. Juxtaposing his experience of capitalism and Darwinian evolutionary theories, Marx (1867) in his formidable work, *Das Kapital*, noted "technology reveals the active relation of man to nature, the direct process of the production of the social relations of his life, and the mental conceptions that flows from those relations" (p.406). Technology is evolving as humans evolve and develop. Basic utilitarian products can be upgraded with the addition of components for other purposes or applications. For example, electricity can be generated through nuclear reaction, combustion of hydrocarbons/natural gas, biofuels, turbines, and solar energy, among others. These energy sources are typically transmitted to consumers through electric cable technology for many years. However, engineers such as Tesla (Electrical Exhibition in 1898) touted the idea and potential technology of transmitting electric energy without cables. He proposed 'inductive charging' or wireless charging technology. After many decades of research, this technology remains explorable (though still not efficient) but viable in an era of digital technology. By embedding digital technologies in Tesla cars, current engineers can remotely send digital signals to these automobiles to be electrically charged if proximate to any charging booth or center.

Thus, technology remains an important component in society especially in the sector of educational research, production, commerce, healthcare, biotechnology, and agriculture to mention a few. A cursory survey of technological trends especially in the 21^{st} century points to the impact of digitization on almost every aspect of technological applications. This has led to the emergence of the term *digital technology* as a distinctive scholarly genre which requires further analysis and discussion.

The term *digital* has become an important concept in the 21^{st} century scientific enterprise. The term has been used and popularized most notably in the 1950s with the axiomatic shift in *analog technology* to digital in computers, household gadgets, data keeping and others (Chase, 1980: Rohdy, 2001). According to Bloomberg (2019), "digitization essentially refers to taking analog information and encoding it into zeroes and ones so that computers can store, process, and transmit such information." A digital technology simply converts and uses data from analog into different and unique forms for an array of reasons and purposes. Digital tools such as computers, smartphones, smart boards, and calculators convert real analog images such as photos, characters, graphs into text messages, and emails, among others. The emergence of AI has been concurrent with the transition of the world from analog technology to digital. The advancement of AI has redefined and reified the contemporary world of technology with new architectures, design an application as a solution to recurring problems, challenges, patterns, among others. The concept and term, *digital technology* connotes very broad applications and contexts. It is evident that the concept "technology" has been in existence for a significant amount of time while 'digital' made it into the academic lexicon in the twentieth century. As Mühleisen (2018) argues that digital transformation is a complex phenomenon and contemporary society must adapt rather than simply adopting these technologies. This dissertation design examined some aspects of digital technologies that has been adopted in the study of STEM as well as what can be adapted to bolster STEM educational activities in the K-12 classrooms.

Furthermore, on their theory of patterns, Alexander et al. (1977) suggest that '…a problem that occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without doing it the same way twice'(p.3) Herbert's (1969, 1973) theory of the *hierarchy-of-parts frame* or principle of near decomposability are relevant and applicable to our understanding of the concept of digital technology. Juxtaposing these theories and other scholarships (Ekbia, 2009; Nambisan, 2016; Mühleisen, 2018), it is evident that hitherto recurring technological frame and architecture in the analog era can be transformed into digital technologies. It involves embedding old technologies with digital components herein digital technology or inventing and designing new technologies with defector digital parts. Indeed, as Simon Herbert (1973) suggested that the concepts of patterns are relevant to digital technology especially in the process of scaling up the lifecycle of a product. For example, textbooks are essential components in science education from K-12 to Colleges and other academic institutions over at least a millennium. Innovators have noted this essential technological architecture of books as well as the other components such as the letters, infographics, and other recurrent and flexible components. Through the application of digital technology, books (hard copies) have been transformed into digital books sometimes by retrofitting these with digital features for users to write or personalized notes, embedded with re/search tools. Educators are also creating digital curricula in response to the emergence of digital technology including blended teaching and learning technologies.

In addition, several scholars have described the concept of digital technology variously (Ekbia, 2009; Nambisan 2016). Nambisan (2016), and other scholars (Dougherty et al., 2012;

Henderson & Clark,1990; Herbert et al., 2019; Inkster, 2012; Kallinikos et al., 2013), advocates for some key elements in describing and analyzing digital technology such as artifacts, platforms, and digital infrastructure. A digital technological *artifact* according to Nambisan (2016) is "a digital component, application, or media content that is part of a new product (or service) and offers a specific functionality or value to the end-user" that includes "either stand-alone software/hardware component on a physical device or, as increasingly is evident, part of a broader ecosystem of offerings that operate on a digital platform" (p.3). This broad definition of digital technology entails apps on computers, mobile devices, biomedical instruments, and equipment, and *fitbit apps* for physical activities (Ekbia, 2009; Nambisan, 2016). Others include smart board apps in schools and other digitized technologies very common in our educational systems in the USA and across the world. Some of these are also found in automobiles such as Uber, Lyft, Maze apps, autonomous vehicles' dashboards (in Tesla, Nissan, Volvo), security and military research, drones, and many other emerging digital technologies.

Similarly, digital technology according to Nambisan (2017) can be construed as a *platform* as they have "…a shared, common set of services and architecture that serves to host complementary offerings, including digital artifacts" (p.4). The key component here is that digital technologies in this context serves as a form of repository and operating systems-hosting many other digital products. Digital platforms possess the essential technological components or framework analogous to the chassis of automobiles in the semantics of symbiotic relationship. That is a host upon which many applications operate. Digital technology as a platform creates endless flexibility for designers, operators, and end-phase users with an embedded capacity to add or generate component based on their utility or needs without having any impact or changes to the original platform. For many years now Android and iOS have been dominant digital *operating* *systems* or platforms upon which many devices operated. Currently, there are other emerging digital technological platforms such as SIRIN OS, Lineage OS, Tizen OS, KAIOS, Harmony, OS, SYNC 3 (Ford) and Ubuntu Touch. These include software suites built into these with executive functions for machines or digital devices. They create a network of communication between a machine's hardware; so, information including digital data can be stored and processed efficiently and expeditiously. The undergirding principle of these digital platforms are AI algorithm and language meticulously engineered to serve diverse digital demands of consumers or end users' unique objectives and applications.

As indicated in the preceding paragraphs, digital technology functions as a platform upon which many end users as well as manufacturers create content including apps, generate data, interface other elements for commerce and STEM education. Digital technology creates and connects communities and institutions, often limited by proximity remotely; and thereby enhances efficiency in communication of information. These elements allow for a further description of digital technology as an *infrastructure* which according to Nambisan (2016), includes cloud computing, social media, and 3D printing technologies. Others include crowdsourcing, crowdfunding systems, digital marketplaces, and digital educational spaces, among others. Social and professional media, including Facebook, Twitter, Instagram, LinkedIn, are classic examples of digital technological infrastructures. Technologies such as Canvas, Blackboard, Socrative apps, Kahoot, R program, Python, institutional and departmental pages are classic examples of digital technological infrastructures. They create opportunities (Brynjolfsson & McAfee, 2014) for efficient communication across learning locations, offer real time educational interactions and exchange of ideas including research in STEM education, among others.

1:5 Characteristics of Digital Technology

Digital technology has the innate capacity to generate new products or technologies, hence the characteristics of ***generativity/combinatorial*** (Brynjolfsson & McAfee, 2014; Yoo et al., 2010; Zittrain, 2006). As Zittrain (2006) noted, digital technological generativity is "a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" (p.1980). This is a common feature within the digital technological artifacts and platforms. They are constantly changing and have exhibited the capacity to continuously create new products, features, or generate new technologies not in the original design or plan (Brynjolfsson & McAfee, 2014). For example, *Skyview* is a popular digital technological app- "generated" or created by combining GPS locations as well as huge data from astronomical collections across the world including maps of the constellation of our galaxy. Users can view almost any and every star, planetary systems in real time with impeccable details and precision for academic, leisure, social and an array of other purposes. There are many applications constantly being created with the combination of both digital technological *artifacts* and *platforms* and hosted by operating systems such as iOS, Android, *SYNC 3Ford*. The operating system acts like digital technological symbiosis in which the "host" (herein operating systems) have the inherent nature and embedded AI and capacity to host novel or new technologies generated. Sometimes, the new systems may be dangerous such as disruptive computer viruses or nefarious programs created within the hosts platforms for surreptitious activities or sometimes for good intents and purposes.

Another example worth exploring is called Scratch. This is a digital technology currently in use in schools and popular among students. It is used for programming, coding, design, mathematics, science, and other applications. It is compatible with many operating systems such as iOS and Android, so it allows users to generate their own data or product, store these data, and recombine these new codes or data for the generation of new programming language not originally associated with the technology. The combinatorial feature of digital technology is significant for STEM education especially in an era of digital culture. For example, the Sphero Educ Robots are compatible with Android as well as iOS operating systems. This feature allows the robots to be used in many forms and purposes on these and a quagmire of other technologically compatible operating systems.

Secondly, digital technology is also characterized by ***re-programmability.*** It is suggested that digital technology can be re-programmed (Yoo et al., 2010; Zittrain, 2008) to the extent that the new product or user phase is completely different in terms of the kinds of AI in the original. In the auto technologies, the *steam engine* was purportedly invented for the mining industries to pump water from mines, a recurrent problem of the time. However, engineers added mechanical components to the steam engines to haul cargo from and to mining sectors and other uses such as transportation (railways) emerged. Since then, inventors have created many "other types of engines" by adding or re-programing original engines with turbos or increasing or retrofitting engines with gasoline combusting components or diesel, culminating with the emergence of new technologies. Engineers have combined digital artifacts and platforms with existing auto technologies such as lane departure warning systems, camera and facial recognition technology, image analyzers, sensors and infrared technology with GPS embedded with engine computers. These technologies have been interfaced with dashboard/infotainment systems to create autonomous land and aquatic vehicles and robots. This has also resulted in the capacity of many automobiles with the ability to store, calibrate and transmit many data such as location and traffic, fuel/energy consumption, engine and brake performance, entertainment, and audio systems just to mention a few in real time to consumers and to manufacturers as apps on operating systems on mobile devices. Examples, Tesla, Mercedes, Ford, Nissan/Renault have these new types of reprogrammable digital technologies. Analogous to these are endless digital technological products and apps in the arena of STEM. Sphero has created many robots with their associated apps and platforms. Apple has allowed its iOS operating technological system to store the apps and data of these robots and programs. Users can write, re-rewrite or re-program the robots and the apps on apple to generate new products, knowledge, and ideas hitherto not in the original manuals or intent of the creators. For example, the Sphero apps and robot have been applied in re-creating geometric coordinates by rewriting new codes, adding new features such as distances and stop codes and using these kinds of information to model and calibrate area, angles, perimeters, surface depths and other geometric features within relatively short periods of time. The same apps allow learners to re-program or re-write new codes to create maze puzzles in which the robots are meticulously re-programmed to move at specific coordinates and distances, and dodge specific objects at specific speeds. These features of *digital technology* have become increasingly appealing in a digital world with significance for STEM education, especially computational thinking and skills needed or required in the 21st century workplace and in many content areas such as language, architecture, arts, painting, design and fashion, and earth and environmental sciences. At the threshold of the NGSS, digital technological capacity to be re-programmable and combinatorial are significant and relevant to accelerating STEM into the next frontiers in the 21st century educational reforms. As Langer (2018) noted, this is creating disruption across organizations in the country and in the world and undoubtedly requires culturally relevant digital responses to teaching and learning STEM from K-12 to tertiary institutions.

Thirdly, digital technology is also characterized by ***expansibility*** (Brynjolfsson & McAfee, 2014; Kallinikos et al., 2013; Yoo et al., 2010). This is the tendency of digital technology to expand or become applicable to other products or applied for other situations not necessarily envisaged from initial designs and production. For example, servers are significant for storing data and other digital information. Modern servers are now crucial in cloud computing as they have additional or expanded roles of backing up data or information from computers, and satellites so these data are offloaded from the personal devices of consumers and optimize their performance. This is also important towards the next generation of digital technology-quantum computing. Current scholarship and data show that digital technology especially around machine learning continues to co-produce and generate knowledge due to the above characteristics.

A cursory look at social media and educational platforms suggests that there is constant information being generated at every second. IBM has reported that "90% of the data in the world today has been created in the last two years alone, at 2.5 quintillion bytes of data per day" (Marr, B. May 21, 2018. *How Much Data Do we create every day?*). The mind-blowing stats everyone should read. At this staggering rate of information or data generation per day, digital technology has become a force to reckon with in terms of our mortar and brick educational systems shaped around textbooks that are often written years or sometime before the academic years. Digital technology does create significant opportunities as well as challenges for our STEM educational systems and activities.

Also, digital technology exhibits the characteristic often described as ***design flexibility*** and ***scalability*** (Henfridsson et al., 2014; Yoo et al.,2010). Digital technology is designed in component parts and easily assembled during production and distribution (Henfridsson et al., 2014; Yoo et al., 2010; Zittrain, 2006). This also allows it to be easily re-calibrated and adapted for other purposes of goals and concurrently scaled up during production. Due to its flexibility, digital technology can also be updated, upgraded, and functionality errors corrected or functionally retrofitted. For example, errors can be corrected by simply sending new apps or programs to users to download either on the web or at specific places or stores instead of recalling entire product lines (Henfridsson et al., 2014). Henfridsson et al. (2014) have asserted that digitized products are reproducible with little or no additional costs unlike analog. For example, a digital STEM book with errors can simply be corrected without recalling the entire collection in the library; and this may be applicable to other digital technologies in education and research. As Henfridsson et al. (2014) correctly noted, "this form of unbounded design flexibility can be traced to the programmability of digitized artifacts and enables more timely responses to a changing environment" (p.4). For example, television LED screens have been re-designed in a way to serve as monitor screens in clinical settings, security and surveillance, and smartboards in classrooms and labs, among others (Henfridsson et al., 2014; Yoo et al., 2010). Amazon Fire Stick, Apple TV and Roku are embedded with technologies that stream news and other media-related information from leading cable networks and activate internet capabilities of the regular LED HD televisions with no direct wiring or cable subscriptions.

On the contrary, this feature can also be deemed risky and can be mis-applied to short-circuit actual and fatal production flaws. A classic example is Boeing 737 Max aircraft. Engineers re-designed the Max with a bigger engine believed to obliterate fuel consumption and optimize performance efficiency. A simulation of the digital technology led to the discovery of some potential flaws with the aircraft. To avoid a recall of the entire fleet, engineers decided on a software design add on with an additional external sensor to correct the defect. Unfortunately, this *design flexibility* of the technology was defective and resulted in at least two fatal accidents leading to an international recall of the entire Boeing 737 Max fleet (Herkert et al., 2020). These examples seem to point to the fact that even though digital technology can be flexible and applied to many contexts with good intent sometimes unintended ramifications lurk.

1:6 Preliminary Conclusion

In brief, the emergence of artificial intelligence (AI) remains unprecedented and with multifaceted applications in almost every part of human endeavor and activity systems including STEM education. AI is simply the ability of non-human entities, herein machines, to exhibit human traits such as logical reasoning, learning including deep learning, and possibility to problem solve (autonomously) among others. Undoubtedly, digital technology is the application of artificial intelligent systems through digital artifacts, platforms, and infrastructure for an array of purposes and uses. Digital technology is combinatorial/generative, reprogrammable, expansive, flexible, and scalable, among others. Due to these features, new digital technologies are ever emerging disrupting almost every facet of contemporary life including the domains of STEM education, research, biomedical sciences, engineering, and data science, just to enunciate a few. This has also culminated in the emergence of a *digital worldview* and concomitant *digital culture* with significance for STEM and education which has been at the core part of the subject matter in this dissertation study.

In this dissertation study, artificial intelligent and digital technology have been used interchangeably unless defined or noted in the contexts. Preferably, the term *artificial intelligent system* (AIS) will be used to mean artificial intelligent and digital technology, broadly construed. And as indicated in the introductory chapter, the study explores the use of *artificial intelligent system* in STEM educational activities, particularly in classrooms through the theoretical frameworks of activity theory (Bødker 1989; Clemmensen et al., 2016; Crowder & Carbone, 2011; Del Río & Álvarez, 2007; Engeström, 2000, 2007; Mills, 2017; Mwanza, 2001;Zinchenko

& Munipov, 1979). As Hasan and Kazlauskas (2013) noted, "activity theory provides us a lens with which to tease out and better understand human activity" (p.9) herein the role of these emergent technologies to STEM educational activities. After all the first principle of activity theory according to Engeström is "…a collective artifact-mediated system and object-oriented activity system seem in relation to networks of other activity systems" (p.78). There is no doubt that digital technologies continue to create socio-economic and educational opportunities for contemporary society as Brynjolfsson and McAfee (2014) have observed. STEM classrooms have been examined as an activity system with specific reference to the Sphero Educ robot as used among some selected teachers. The Sphero Educ Robot exemplifies an *artificial intelligent system*. This is because it has an AI component in which it can learn and follow codes, or patterns written for it, as well as re-configure some of these commands in other areas of STEM. The robots have digital technological components as well. For instance, code syntax is digitally present and communicated between learner, teacher, and the robots. As Vygotsky (1978) insightfully noted, activity is simply "the dialectic relationship between subject and object" that is "who is doing what, for what purpose". In this perspective, I consider the technological frontier in STEM education as an activity system in advancing teaching and learning. As Brynjolfsson & McAfee (2014) noted, "…even scientific discovery, the key to winning the race is not to compete against machines but to compete with machines" (p.36) especially in the emerging frontier of *artificial intelligent systems* of contemporary digital culture or digital worldview which requires further inquiry.

1:7 Digital Worldview and STEM Education

The worldviews or cosmological purviews of many societies have exhibited some amorphous perception of artificial intelligence and related technology. Shashkevich (February 29,

2019) insightfully reminds us that "our ability to imagine artificial intelligence goes back to ancient times. Long before technological advances made self-moving devices possible, ideas about creating artificial life and robots were explored in ancient myth" (para.3). The *ideas* and the seeds of artificial intelligence can be found in folklore and recorded history in virtually every known civilization. In a seminal book on the subject matter entitled, *Gods and Robots: Myths, Machines, and Ancient Dreams of Technology*, Mayor (2018) poignantly notes that Hellenistic mythologies cusped in the semantics of "artificial intelligence" existed. Works of Hesiod (700 BC) for example explicitly encapsulated vivid expose on *Talos*- a giant figure endowed with automated prowess capable of *self-movement* in protecting Crete. In addition, Virgil's *Brazen Head* was reputed to have a capacity to communicate with its users akin to contemporary forms of artificial intelligence and machine learning. In some African cultures, myths abound regarding witches flying in the night on varieties of oval-shaped objects with whisks or broom sticks as control guides analogous to modern day drones. As one of the earliest researchers, Debrunner (1961) observed about flying witches: "Then they begin to glow. The extremities begin to glow especially the mouth which glows like a fiery ball. They go out emitting flames from their eyes, nose, mouth, ears, and armpits" (pp. 20-21). These descriptions and others offer insights into the scientific worldviews of pre-colonial African epistemologies (Mesaki, 1995). Axiomatically, these *zeitgeists* (prevailing intellectual aura/mood of the time)-ideas and indigenous worldviews were dismissed as pseudo-science in most early scientific papers (Braun et al., 2016; Dei, 2006; Manzini, 2002; Ogunniyi, 1988; Sutherland et al., 2002). According to Mesaki (1995), scholars including social scientists, anthropologists among others did not hold favorable views and were apparently swift and dismissive about the phenomena. Refreshingly, current scientific innovative tools in avionics, drone and digital technologies can model these in three dimensions (3D) to impeccable precisions.

These earlier references to artificial and cognitive intelligences, though cusped in popular mythologies at the time, can be modelled in the contemporary world of digitization (Glen, 1989; Good, 1987; Popenici, 2017). Hence from hitherto mythological worldviews, scientific researchers can and do model some of these technologies with diverse applications in real life. These give credence to the significance of worldviews and cultural contexts (Emdin, 2007) in the construction, and co-construction (Jasanoff, 2007) of knowledge especially in science education (Gauch, 2009; Irzik & Nola, 2009; Matthews, 2009; Schraw et al., 2002; Spiro, 1998).

Furthermore, teaching and learning occur in definitive spaces, time, and cultural milieu or in hermeneutical semantics, in a *sitz-im-leben* or social context (Alvarez, 1995; Daniels, 2001). The social contexts, herein the worldviews of learners, educators, their experiences, and unique epistemologies, create cognitive culture (Schraw & Olafson, 2002; Sirrakos & Emdin, 2017: Spiro et al., 1996; Vander et al., 2015). This encapsulates the extent and variation of interaction with their environments, personal and social interpretations, and meanings of the world as individuals and as a society. In other words, there exists a cognitive as well as a social culture/worldview peculiar to every person or individual in any socio-cultural context.

In a broader sense, a worldview includes cultural appropriation of relevant technologies of the time into the teaching and learning spaces either formally or informally. This is because teaching and learning are inextricably linked with the environment in which learners undergo some form of epistemic shifts or conceptual change leading up to the co-construction of new forms of knowledge. Indeed, as Guba (1990) noted, a worldview simply is “a basic set of beliefs that guide action” (p.7). I believe each learner’s worldviews and contexts correlates with their intrinsic capacity for creating knowledge. Scholars have been keen in analyzing and offering insights into the notion of worldviews of learners and teachers and in fact in society generally as this has implications for education. As Jenkins (2007) further noted, "because this sense of reality determines how an individual relates to other individuals, the way they express themselves in behavior and language enable us to learn about the cognitive worldview" (para.13) of individuals and their respective societies. This provides a kind of preliminary framework for understanding their perception or experience of the natural world and how this affects them in their relations with other groups, especially in education. In Part One, Book Two, Section 26 of the *Critique of Pure Judgement*, Kant (1987) also postulated the idea of a worldview (*weltanschunng*). Juxtaposing two German words, *welt* (world) and *anschauung* (view), Kant (1987) averred:

> If the human mind is nonetheless to be able even to think the given infinite without contradiction, it must have within itself a power that is supersensible, whose idea of the noumenon cannot be intuited but can yet be regarded as the substrate underlying what is mere appearance, namely our intuition of the world [***Weltanschauung***]. For only by means of this power and its idea do we, in a pure intellectual estimation of magnitude, comprehend the infinite in the world of sense entirely under a concept, even though in a mathematical estimation of magnitude by means of numerical concepts we can never think it in its entirety. (pp.111-112)

The key concept here is that as rational intellectual entities, human beings first and foremost experience of knowledge is predicated on their worldviews. This includes their perception of reality, imaginations, ideas, concepts tacitly or explicitly in their unique and definitive *sitz-im-leben* or socio-cultural context (Alvarez, 1995). It also includes their interaction of finite everyday things (Alvarez, 1995; Engeström, 2007) such as the food they eat and how it is even prepared and associated technologies, the arts including music, prevailing sub-cultures such as hip hop, pop culture, sports to the infinite intellectual life such as their learning habits and kinds of educational spaces of their world. Rather, each person has an epistemological inclination extrapolated from their perception of the world and their respective worldviews. Thus, the way people view the world including their experiences, interactions in everyday life to some extent shape their ability to construct and comprehend the intellectual life and, in this vein, the world of science (Coulson et al., 1996; Daniels, 2001; Lindqvist, 2003; Matthews, 2009; Olafson et al., 2015; Vygotsky, 1978).

According to Nietzsche (1980) ‘‘every living thing can become healthy, strong, and fruitful only within a horizon’’ (p.10) or a worldview since ‘‘the only seeing we have is seeing from a perspective; the only knowledge we have is knowledge from a perspective’’ (Nietzsche, 2009, p. 98). Heidegger (1927) also expatiated on this notion of worldview and postulated that it is ‘‘a self-realized, productive, as well as conscious, way of apprehending and interpreting the universe of beings” (p.5). In other words, human beings have the experience of their own world as it is and the capacity to add some luster of meaning to it by their own interpretations of these experiences because they ‘‘grow up within such a worldview and gradually become accustomed to it. . . It is not simply retained in memory like a parcel of cognitive property’’ (p.5-60). On the contrary, human beings are the true interpreters of their own experiences of the world. This has implications for educators especially in the arena of STEM in our contemporary times satiated with digital technologies and concomitant emerging digital cultures. As Stephen Hawking posited some thought-provoking question in his book, *The Grand Design*, "How can we understand the world in which we find ourselves? How does the universe behave? What is the nature of reality?” (p.5). These questions on the nature of reality in science shift the lenses of the nature of science to the worldviews of individuals' epistemological ecologies. In fact, as Aerts et al. (1994) have noted, a worldview simply “…is a coherent collection of concepts and theorems that must allow us to construct a global image of the world, and in this way to understand as many elements of our experience as possible" (p.17). Thus, learners' worldview inexplicably has profound implications for culture and is pivotal for the construction of scientific knowledge. As a prominent contemporary scholar, Emdin (2016) poignantly notes, 'these populations are the early adopters of a number of major technological breakthroughs and social media platforms because of the way the technology aligns to their forms of cultural exchange. Just as hip-hop culture re-calibrated the norms of music production technology and shaped the ways that microphones, speakers, and turntables were designed and used, the neoindigenous have done the same thing with social media" (p. 194). Scientific process and associated technologies do not occur in a void but are precipitates of prevailing worldviews and perceptions from tacit experiences into critically organized scholarship. There is no iota of doubt that students and educators are living in a world that is drenched with digital technologies compared with many prior generations (Graesser et al., 2013; Hu et al., 2013; Olney et al., 2007). In other words, it is an environment that can be described as a digital culture (Graesser, 2007; Masie 2005). As some scholars (Buckingham, 2006; Greaser at al., 2013; Palfrey et al., 2013) have observed, there is a seeming dichotomy in cultural experiences or current populations partly due to different experiences of the world and AI associated technologies culminating in digital culture/worldview. There is an insatiable transformation under the aegis of digital culture in our society today (Bonks, 2009 & 2015; Holbert, 2002; Korneru, 2010; Langer, 2018; Masie, 2005). This apparent phenomenon continues to redefine contemporary demographic's experience of the world thus creating a new worldview-indeed a zeitgeist of *digital multicultural grid* of significance for STEM educational activities.

Current demographic worldviews can be differentiated coterminous with digital experience or associated AI technologies (Abbey, 2000; Bonk et al., 2015; Herring et al., 2006; Prensky, 2013). There is a segment of society who were born into an era dominated by digital technologies such as web technologies (web 2:0), big data analytics, data mining, mobile computing, autonomous robotics, and an avalanche of others. Their worldview has been shaped by digital culture and technologies. They are highly interconnected, exhibit on-the-demand digital habits, access information quickly and exhibit proclivity to multi-task. While others, including some of the pioneers and investors of the AI associated information technologies, lived in an era without the internet or limited access to (the web 1:0) and in some situations with no access to digital technologies. From the context of the exposé on worldview above, these groups of people have different and unique worldviews shaped by AI technologies. So, their cultural experiences and prevailing worldviews, including perceptions of reality, differ significantly (Anderson et al., 2004; Barrett, 2012; Combi, 2016; Rhoads, 2015; Richards, 2003; Levy, 1999). Digital technology has indeed created a digital worldview symptomatic with an emergent digital culture (Bonk, 2009; Hew et al., 2007; Sitzmann et al., 2006). AI digital culture and associated worldviews are disrupting organizational and institutional structures and practices in almost every fabric of society post the industrial revolution (Langer, 2018). As Mayor (2019) notes, *there is a timeless link between imagination and science*. Human imagination is shaped by prevailing worldviews and these worldviews inexplicably become the silage for scientific epistemological ecologies, socio-cultural and cognitive development, and learning (Jegede, 1997; Schraw et al., 2002; Spiro et al., 1996). As Vygotsky (1978) also noted in his famous sociocultural theory of learning:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals. (p. 57)

Therefore, learners are inundated with AIS of many kinds. From birth until formal schooling age, children are increasingly interacting and spending copious time with AI-laden technologies such as computers, mobile devices, electronic games, digitized homes and at other places of cultural activity. And as a recent BBC (British Broadcasting Corporation) technology research report article noted "The main difference from the 1990s is that then TV and magazines were the main ways for connecting kids to the media and now they have different devices from tablets, mobiles, games consoles and they have a much higher screen time" (Navard, 2015). There is thus a shift towards digital social interactions in our current *interpsychological* or *socio-cultural* as well as *intrapsychological levels* compared to earlier social groups and sub-cultures. Understanding these through the lenses and words of Vygotsky, "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (p. 86), could potentially be mediated not only by human beings such as teachers and peers, but by AI tutoring systems, deep machine learning domains among others creating a *trialogue* (Graesser, 2016). According to Graesser et al. (2016) trialogues is a three-party conversation analogous to the interaction between a student and a teacher/tutor ostensibly in a learning and pedagogical context. For example, *Beacon* (an AI robot chat) is currently available (downloadable as an app) to some educational institutions in the UK. *Beacon* has been programmed to perform myriads of tasks tailored to students' needs such as scheduling their classes, answering course questions, clarifying homework, explaining concepts through voice or text messages, and even linking learners to experts and professors in real time. Several of these AI trialogues such as AutoMentor, DeepTutor, iSTART, iDrive, Operation ARIES. DeepTutor have been developed as an "intelligent tutoring system" and some students are currently using some of them to augment their STEM classes covering many topics (Hu et al., 2012; Johnson et al., 2015; Olney et al., 2012; Rowe et al., 2010; Ward et al., 2013; Wolfe et al., 2015; Zapata-Rivera et al., 2015).

So, in addition to the Vygotskian interpsychological cultural development, AI technologies are increasingly significant in creating a new forum for learners to interact with non-human intelligent entities in their understanding of the world in an epistemological alignment with their digitized worldviews as well as their learning pathways. As we have noted earlier in this chapter, AI technologies are combinatorial and generative (Brynjolfsson & McAfee, 2014). Learners can combine intelligent machines or apps with different kinds to co-create or generate new information and knowledge of exponential proportions. And a new meaning about the world emerges each time learners either as individuals or collectively share a common digital platform for communications, play a video game together, or code together with their computational devices to generate or impose new meanings to their experiences with AI systems in any domain. In a similar perspective, Cobern (1991) also postulated,

> beginning in childhood, each person interacts with his or her physical and social environment, and through this myriad of environmental interactions, world view presuppositions are unconsciously constructed. The process occurs over a long period of time, with the formative, childhood years being of most importance. Through the years of schooling, formal education contributes to world view development; and in turn, a world view provides a foundation upon which cognitive frameworks are built during the learning process. (p. 21)

This observation and truism are critical and relevant in the discourses on AI and science education in contemporary times of learners. Learners worldviews are constructed and informed by significant interactions with digital technologies either consciously or unconsciously to the extent that some scholars such as Brynjolfsson and McAfee (2014) have asserted that the AI phenomenon has culminated in "…new ways of acquiring knowledge…and higher rates of innovation" (p.6). For example, by combining an old technology, GPS (Global Positioning Satellites) system with maps, Uber and Lyft have created multibillion transportation industries transcending every continent. As a result of these combinational effects of digital technologies, there have been copious infusions of capital in research and development (R&D) across major auto corporations. Students, teachers, and many people across every specter of society are coding or participating in some form of co-inventing, investigating some aspects of artificial intelligence out of the curiosity of it or striving to intentionally solve an enigma. These synergies are seemingly consistent with the current on the demand-service oriented worldview of our generation. AI is creating forums for social interactions as well as generating new corpus of knowledge-based or domain systems.

As noted above, there is an emerging generation associated with the development of AI whose concepts of the world and social connections, including language, seem unique with implications for educators and socio-economic production. By inference, digital culture has the potential of impacting the cultural developmental worldviews of the child and later his/her cognitive development at school. This is generating a new thrust towards a paradigm shift in science education requiring a critical examination of the two dominant philosophies of education which have shaped the goals of education post the industrial era- the instrumental and the developmental. The instrumental approach, which vacillates on the premise that educational goals entail the training and formation of learner's skills towards the gamut of economic productivity while the developmental approach under the expediency or the idea that education enhances human development. That is, each person has the inherent right to be educated according to their age or culture, and to be responsible citizens of their respective societies.

Contemporaneously, artificial intelligence and cognitive intelligent machines have the capacity to replace *educated skilled workers* in many areas of the economy. These include manufacturing robots, drones for essential deliveries, data science tools (R program, Python) for huge data analytics, autonomous vehicles, bioinformatics tools for DNA and biologic modeling and analysis and an avalanche of others. In neuroscience, some AIS can perform some of the developmental roles such as language, diagnostics, behavioral predictions, and others. In view of these, there seem to be torsional strains among scholars as to the goals and the *raison d'etre* of current and future education. While some scholars (Bloomberg, 2018; Bonks et al., 2015; Noonan, 2018) speculate that digital technologies will dislodge employment, there is little evidence that this is happening.

On the contrary, there is reason to believe that digital culture will rather create different economic landscapes that will require experts in AI such as code writers, machine managers and operators, an array of workers with computational thinking skills. As a result, education will evolve in response to these changes (Bonk et al., 2015; Brynjolfsson & McAfee, 2014). As a result of the relevance and ever emerging trends of digitization, there is renewed impetus to explore and understand the current demography. Some scholars (Brynjolfsson & McAfee, 2018) have reported the possibility that some workers might not be up to date with digital and other computational skills to be relevant in contemporary economic workforce. Other scholars (Prensky, 2001) have offered some insights and categorizes the current demography into digital immigrants and digital natives. The former according to this taxonomy are associated with the inventions of the AI associated digital technologies while the latter (born after the 1980s) grew up in a worldview coterminous with these technologies such as the web technologies, text messaging, social media and other instant forms of communications, autonomous devices as well as a world of robotics. Some scholars (Arafeh et al., 2002; Bennet et al., 2008; Buckingham, 2006; Palfrey & Glaser, 2013; Prensky, 2001) have researched into this apparent dichotomy among digital immigrants and digital natives with dire findings. Some recent researchers, Arafeh et al. (2002) have noted in a recent study that a dichotomy exists between students and contemporary school culture when it comes to digital technological access and applications to teaching and learning. These challenges were evident during the beginning of the COVID-19 pandemic where many schools lacked and lagged in these technologies necessary for teaching and learning. These situations may posit some challenges and concurrently create some opportunities for educators to adapt to the AI trends. As Darwin once noted, *it is not the strongest of the species that survives, nor the most intelligent; it is the one most adaptable to change.* The emergence of new AI technologies calls for adaptations in the arena of socialization especially in educational domains of teaching and learning throughout the lifespan of learners. This will require a culturally relevant and responsive pedagogy to reflect these new worldviews and shifts in digital culture and unique experiences in the domains of curriculum designs, content generation, classroom arrangements and methods. As some prominent scholars, Snow et al., (2017*)* have noted,

> increasingly, organizations are assessing their opportunities, developing and delivering products and services, and interacting with customers and other stakeholders digitally. Mobile computing, social media, and big data are the drivers

> of the future workplace, and these and other digitally based technologies are having large economic and social impacts, including increased competition and collaboration, the disruption of many industries, and pressure being put on organizations to develop new capabilities and transform their cultures. (p.1)

Many technology-based entities such as Google, Microsoft, Facebook, IBM and others are actively collaborating with educational institutions and organizations including policy makers and think-tanks in the process of digitizing libraries and learning platforms and spaces. Publishers are offering options of electronic books(e-books) for authors and consumers and in the arena of science education. Digital technology and associated culture are disruptive and as Brynjolfsson & McAfee (2014) insightfully postulated, “each development becomes a building block for future innovations” (p. 62).

Consequently, the current educational models on the industrial revolution and capitalism is seeing a seismic shift of exponential proportions. And it is anticipated to pave way for something completely new. Analogous to Hegelian dialectics, digital technology may seem antithetical to current educational philosophies and constructs. This is because most digital innovations are taking place outside of the confines of educational institutions and students are highly immersed and technologically skilled. And as noted above, this dichotomy may continue to create tensions within educational organizations. In response, some educational institutions are embracing these novel digital technologies in accordance with their organizational structure albeit hierarchical. In this vein, head of educational institutions through their technology departments are making decisions about incorporating digital technologies into their educational and learning systems and spaces (Langer, 2018). Indeed, the frequentation and the vim with which these AI related technologies emerge to some extent is indicative of the acceptance and applications in almost everyday life including education. The versatility of AI is seen in teaching methodologies (Hew et al., 2007), tutoring (Graesser et al., 2013), content development (Bonk et al., 2015; Mishra et al., 2006), educational diagnostics and data analytics, adaptive and differentiated learning, and many applications. This trend often referred to as blended learning is reflective of the trajectory of 21st century educational practices. It is creating opportunities for many people to access education easily such as *Massively Open Online Courses* (MOOCS), greater educational collaboration and networking, reducing replication of scientific research thereby ameliorating costs associated with some scientific discoveries. It is anticipated that these will ultimately revolutionize educational systems completely. To use the words of Kuhn, AI is seemingly creating *scientific communities* where collaborative and social learning occur in real time generating unprecedented co-production of scientific corpus of knowledge for the common good. Indeed, as some scholars such as Chassignol et al. (2018) have noted, AI has some plausible educational impact such as customized or personalized educational content, and innovative teaching methods such as project-based learning. Others include technology enhanced assessments, learning progression, communication between students and teachers and creating "digital culture into our schools". Thus, contemporary learners' digital world has created their own unique worldview-digital-view driven by AI technology. New and emerging digital concepts associated with AI are common features of their worldviews and existential experiences transcending their daily lives and educational spaces. This has ultimately created a new digital culture or a culture of digitization and global connectedness with significance for teaching and learning of science education. Others do so in collaborative ways by bringing all stakeholders within educational institutions to incorporate and create their respective digital cultures. These culminates in a new thesis in Hegelian terms. However, it is worth noting that “self-organization and collaboration, as an adaptive response, is faster and more effective than a hierarchical response” (Snow et al., 2017, p.3) because technological disruption changes established and entrenched institutional structures (Endsley, 2000). Indeed, as Kuhn (1996) noted in his formidable work, *The Structure of Scientific Revolution*, such a situation will create “chaos” prior to the scientific (herein technological) revolution and paradigm shifts in science education.

At the frontiers of education, digital worldviews and associated digital culture in our schools today poses some existential and pragmatic challenges. Put subtly, there is a genuine appreciation of the role of artificial intelligence in the co-production of knowledge. Others include boosting pedagogical culture and embellishing educational practices as well as potentially disrupting the role of the human interface in teaching and learning science education. On a cautionary note, one of the prominent scientists in contemporary times, Stephen Hawking (2017) insightfully advises in a recent CNBC segment:

> Success in creating effective AI, could be the biggest event in the history of our civilization. Or the worst. We just don’t know. So we cannot know if we will be infinitely helped by AI, or ignored by it and side-lined, or conceivably destroyed by it” … “I am an optimist and I believe that we can create AI for the good of the world. That it can work in harmony with us. We simply need to be aware of the dangers, identify them, employ the best possible practice and management, and prepare for its consequences well in advance.

Furthermore, Heidegger (1927/98) postulated that a worldview "grows out of an all-inclusive reflection on the world and the human *Dasein* and this, again, happens in different ways" (p.5). AI has become part of life and each person or learner experiences it in different ways in accordance with their unique socio-cultural contexts and expectations. As Paulo Freire once noted, *education does not change the world. Education changes people. People change the world*. AI cannot change and transform education per se. Rather, digital culture and worldviews if incorporated into educational culture will have the desired impact in effecting changes. The existential reality is that Al will remain a core part of science and technology education. The extent to which AI is integrated in these areas of science education will have ripple and epistemic effects on current and future citizenry's scientific output and literacy. As one of the recent polls suggests, about 41% of respondents have a positive view of AI and are opened to its development. Interestingly, 57-59% of college educators and high-income earners believe AI should be developed. Thus, the social interest regarding the development and application of AI is unprecedented. As indicated in the HS Engineering Design of the NGSS, "new technologies can have deep impacts on society and the environment, including some that were not anticipated…" (NGSS, 2015, p. 98). It should be noted that the current pods of students described by demographers as technology generation grew up contemporaneously with the advancement of digital culture (Palfrey et al., 2013). From pre-k to upcoming college students can without a doubt be described as *technology generation* whose worldviews and educational experiences have a significant iteration with technological grid especially artificial intelligence. As Heidegger (2011) notes,

> by setting its essence upon itself, the human rises into the willing of its own self. With this up-rising [*Aufstand*] of the human into the will as the willing of itself, all things simultaneously become an object [*Gegenstand*] for the first time. The human

> in this up-rising and the world as object belong together. Within the world as object, the human stands in the up-rising. The up-rising human only admits the world as object. Reification *[Vergegenständlichung]* is now the fundamental comportment toward the world. The innermost and today still-concealed essence of the reification, not its consequence or even just its mode of expression, is technology. (p. 20)

In perspectives, students and teachers' experiences of the world and themselves are somewhat unified and are reflections of AI driven technology. As the world demands for AI-based technology propitiates, it is anticipated that current educational cultures adapt to such trends and needs. As society relies increasingly on AI technology for the means of production, commerce, medicine, transportation, security just to enunciate a few, so will education evolve to these changes in a symbiotic fashion to remain relevant as a reification of technology. And these are part of the minefields of students' worldviews in our educational institution, especially in STEM. Technology drives the world (Langer, 2018). It can be a positive disruptor and sometimes negative. There is an explicable correlation between science and technology. Hence, science education and technology intersect. Thus, current technological transformation as noted in the introduction has the implicit capacity to transform curriculum design and science policy, teaching, learning, assessment and all the gamut of education. Increasingly, students and teachers seem to have diverse digital cultural and technological experiences sometimes at variance with each other. For instance, while some teachers perceive students' use of mobile devices as "disruptive" recent studies conducted by Cho and Littenberg-Tobia (2016) and others have demonstrated that if harnessed, mobile devices can improve student's literacy and by extension, science educational experiences. With the eminence of the fifth generation (5G) wireless technologies and the potential or capacities of the next generation of mobile devices, a new set of attitudes and educational digital culture will emerge or will have to emerge to incorporate these into mainstream traditional teaching and learning space. This will lead to some form of *co-teaching* in the semantics of reality-pedagogy (Emdin, 2016) for both educators, administrators, students, and even parents. Hence my research is to critically examine how digital culture under the aegis of AI could transform and enhance teaching and learning of STEM (Buckingham, 2006; Combi, 2016; Fogarty et al., 2011; Graesser, 2016; Hu et al., 2012; Olney et al., 2012; Palfrey et al., 2013; Rowe et al., 2010).

1:8 Some Challenges

Although there is much enthusiasm and optimism about this transformation of science education, and education more broadly, there have been some concerns about the current generation and their experience and use of digital technologies. In a recent study, Gardner and Davis (2013) argue that though digital technologies are of immense benefits to current generations and their dispositions towards learning, they nonetheless suggest that “with respect to imagination: Apps can make you lazy, discourage the development of new skills, limit you to mimicry or tiny trivial or tweaks-or they can open up whole new worlds for imagining, creating, producing, remixing, even forging new identities and enabling rich forms of intimacy”(p.33). In other words, there is a possibility that young learners may become over reliant on technologies and inordinately dependent on the digital technological grid to the detriment of their creative skills. Combi (2016) also postulated the thesis that the current digital generation is losing a sense of time. People continuously have access to the digital cultural grid; thus, coalescing the notion of past, future into the present but uninterrupted moments. Some people switch-on their computers, mobile devices and other electronics and continuously stay on these devices and on the internet. Indeed, a cursory observation in the real world can prove this concern. It is not out of place to see people walk across busy streets, at lecture halls/classrooms, doctors' offices during appointments, driving, while concurrently browsing the internet or having some iteration with digital technology. Consequently, there seems to be relatively little time to reflect on the past to understand, relate and project the future.

Another challenge associated with digital technology is the speed and alacrity with which information gets propagated by web technologies. Some scholars (Combi, 2016; Levy, 1997) have pointed out that there is the tendency to presume every information generated and available on web technologies and associated digital technologies to be true and accurate. Such proclivity undermines critical thinking and analytical skills required in science education. These calls for constant curation of web-based information and data especially in research methodology and STEM.

Furthermore, according to a recent startling data and report from the World Economic Forum (May, 2016) it has been estimated that between three to four billion (3-4 bn) people do not have access to the internet and/or reliable information technologies. The report in pertinent part notes that "one reason many people aren't logging on is simply that a good, fast connection is not available – 31% of the global population do not have 3G coverage, while 15% have no electricity. In sub-Saharan Africa some 600 million people (almost two thirds of the region's population) do not have regular electricity, and this applies to nearly a quarter of people living in South Asia". In the USA, a recent Pew Research Report compiled between 2013-2019 shows a disproportionate number of students lack access to quality and reliable digital resources. According to this report, "roughly three-in-ten adults with household incomes below $30,000 a year (29%) don't own a smartphone. More than four-in-ten don't have home broadband services (44%) or a traditional computer (46%). And a majority of lower-income Americans are not tablet owners". These data seem to give credence to the presumption about the dire socio-economic indices of our global demography. There is a significant disparity among students' ability to access the digital technological grid and the tools needed to succeed in a 21st century educational system due to their respective economic status. This is a recipe for creating injustice and inequity within our educational system. The middle and working class are depleting at an unprecedented rate. Given the correlation between income and accessibility to technologies, and teaching-learning resources, there is a probability this trend will sustain the huge technology gap with an emergent digital *divide*. As we roll out the NGSS and other novel science curricula, we are once again confronted with the challenges of AI technologies and the culture it is creating. Current students hold the potential for the next generation of the workforce and human capital. Evidentiary, some sectors of the economy are phasing the human interface with robots and other autonomous machines. While some scholars (Brynjolfsson & McAfee, 2014) believe this will not replace the entire workplace *per se*-although it may cause unemployment, there is the fear of the unknown.

Notwithstanding the above, the history of science has shown that the radio, railway, and telephone technologies took many years to change the workplace dynamics and ultimately educational sector (Bonks, 2013). However, digital technologies such as the internet, reached millions of people within a short period of time. By inference, a lack of access to digital technologies and associated culture has the potential of creating substantial socio-economic disparities including education. Analogous to Plato's allegory of the cave, it seems a significant segment of contemporary demography and cultures are confined to the worldviews of the dark cave of digital divide and the possibility that they will emerge out of such situation and experience the full glare of digital technological grid and culture and the endless oasis of opportunities therein remains apparently elusive. Even with the rapid diffusion of artificial intelligent systems and digital technologies, some students and educators do not have access to high-speed internet in their schools. Others rely on almost extinct analog and dial up technologies to access the information highway. Some schools with access to these technologies may have educators who have little or no experience and deemed digitally quasi-illiterates. Some schools do not have adequate labs that are by standards deemed well equipped or resourced. While virtual reality technologies could augment these to ensure teaching and learning, unfortunately, current policies on funding schools contingent on zip codes and geographical indices can create a gulf of opportunities for socio-economically dislocated communities. That raises the barometer for injustice as education is a fundamental human right properly within the loci of economic and other opportunities. Lack thereof of equity in access to quality digital and AI driven technologies in the pursuit of science education can truncate socio-economic growth and displacement of equitable and fair opportunities for all (Rawls, 2005).

1:9 Some Perspectives

In conclusion, AI systems are opening new artesian wells for educational opportunities and applications, charting new methodological pathways, content creation and curriculum design, career preparations and indeed a seemingly new paradigm shift in science education. Technology is changing teaching and the learning environment and obviously the worldviews of learners and educators. In a thought-provoking book entitled, *The World is Open: How Web Technology is Revolutionizing Education*, Bonk (2009) describes a captivating scene of a 19th century or earlier researcher had to travel by horse to a library, walk the hallways to mountains of bookshelves and scrolls, and perhaps ask scribes to laboriously copy pages of research interests. This process probably could last days or even weeks to just *access information.* In contradistinction to this, AI *web technology* has constricted these laborious processes to a few seconds in accessing and retrieving reliable and curated information! Access to information is key to learning and acquisition of knowledge. The emergence of the web and associated technology has since launched education and learning into the orbit of the information pathways. As Alam and Kenda (2018) have noted, many traditional professional functions of an educator remain unpredictable in the wake of such epistemic changes. AI technology especially neural technologies may give insight about how students process information and learn. Sana Lab AI currently has the capacity to diagnose learning habits of students. These are ultimately useful as teachers can align, personalize, or adapt their pedagogy and content with their respective students. It can also help educators determine the amount and kinds of content to present to students as well as differentiated assessments and grading among a medley of applications. There is thus a proliferation of information and data overload due to these technologies and other forms of AI driven technologies. Such an information pathway is an opportunity for science educators to collaborate to construct as well as deconstruct epistemologies relevant for improving teaching and learning STEM. Apps such as Socrative, canvas, google classroom, deep machine learning AI tools and others are available to science educators to create micro and macro pedagogy and digital subcultures in content areas or digital pathways in their respective schools. As Montgomery et al. (2016) noted, *"science by definition, implies universality. As the systematic study of nature, we typically assume that science is as universal as the subjects it examines"* (p.1). AI technological grid can virtually become universal platforms for educators and learners to collaborate in advancing science education. Finally, it is anticipated that the disparity between science teachers and pre-service teachers and secondary students attitudes especially about AI driven digital culture including machine learning will be further explored. For instance, what amount of AI technologies do science educators experience in comparison to their students? As the NGSS is being rolled out nationally with implications for other countries, how will AI affect STEM education? How are teachers applying AI to impact science teaching and learning and how do students also culturally respond to these for optimal educational experiences? These and a flurry of other questions requires further inquiry and study amid the current digital worldviews and the concomitant digital technologies.

Chapter 2: Theoretical Framework

2:1 Activity Theory: An Introductory Comment

Some captivating headlines in reputable scientific journals, such as *Nature* (Callaway, 2016*)* and *Science* (Goodall, 1998) indicated that primates can shape wood and stones into "tools" for specific purposes. While these apparent technological feats have been documented over many years and across almost every continent, primatological activity with tools are significant precursors to human driven activity (Engeström et al., 2007; Goodall, 1998). As some scholars have consistently pointed out, human beings by nature are activity driven (Chaiklin, 2003; Engeström et al., 2007; Foot, 2014; Vygotsky, 1978). Meaningful activity is central to the evolution of human existence and adaptational survival at different circumstances and conditions. As social entities, human beings engage and interact with the natural world and with each other at many levels and for various reasons. These activities may be intentional or by virtue of our affiliations in the social structure (Alvarez, 1995). Human activities are conspicuous in everyday social activities such as family interactions, agriculture, commerce, transportation, healthcare, security, and education. Such activities can be physical and /or physiological (Engeström et al., 2007; Hasan & Kazlauskas, 2014; Krinski, & Barker, 2009; Oers, 2010; Vygotsky,1987) and necessary for survival. Physical activities include moving from one place to another, participation in commercial socio-economic and agricultural ventures. Others include designing and building, and construction of edifices and places of residence, among others. Physiological activities include conception of ideas; planning and the use of language both verbal and non-verbal communication (Engeström et al., 2007 and 1999; Hasan & Kazlauskas,2014; Waycott et al., 2005; Vygotsky,1987) have been documented across every cultural milieu. However, these portmanteaus of activities are typically accomplished using tools, artifacts within the purviews of their geophysical location and social contexts (Callaway, 2016; Engeström et al., 2007; Kuutti, 1996). Historico-phenomenological evidence suggests that cultures have used many tools during these interactive activities either covertly or overtly or as a necessity to attaining their objectives (Engeström et al., 2007, 2009 and 2010; Hasan & Kazlauskas, 2014; Krinski, & Barker, 2009; Oers, 2010; Vygotsky,1987).

Early humans and civilizations used many artifacts and technologies to engage in viable activities resulting in drastic transformation of their societies and social arrangements. For instance, during the Paleolithic era (stone age), lithic analytic and anthropogenic evidence suggest that human beings used stones as tools in almost every component of their lives. Stones were meticulously engineered and shaped into various tools for many purposes such as hunting, grinding and the excavation of their environments (Key et al., 2020; Mora et al., 2005). As population became expansive and quasi-sedentary, early cultures invented many complex technological tools and artifacts in response to their specific needs and culture. As noted earlier, the wheel was invented as a necessary versatile tool for transportation, mining, agriculture, and building, among others. Of course, the addition of the wheel to horses meant cultures had access to unprecedented tools and horsepower capable of moving from one place to the other. With persistent droughts in their horizon, some early cultures tapped into artesian wells and aquifers with new technologies such as hydraulic systems (Pfaffenberger, 1992). Modern humans continued to use many tools to engage each other in the exploration and an understanding of their natural environments. Galileo for instance designed one of the most efficient and modern telescopes which has become an important scientific and technological tool till this day. Obviously, these have culminated in new interests in space and astronomical science and mathematics. But human activity is not limited to physio-physical activities. As intellectual entities, human activity is also cognate as they make *meaning* of the abstract world. Human activity at the cognate levels is evidential in the myriads and corpus of scholarship that have survived and continue to saturate the world, sometimes beyond the assimilative powers of each generation. Indeed, as Aristotle noted in the opening paragraph of his *Metaphysics*, human beings by their very nature desire to know. This desire remains a form of activity albeit an intellectual one in the social construction of knowledge (Alvarez, 1995; Daniels, 2001; Jasanoff, 2004: 2-3; Vygotsky, 1978). As early humans used stones and sticks as tools (albeit technologies) to engage in meaningful activities, so do current digital worldviews and culture and concomitant artificial intelligent systems and digital technological tools.

In brief, both the physical and intellectual human activities are pursued using some form of *technology*, culturally mediated and often aggregated in knowledge creation, and emergence of new tools and novel technologies within each *sitz-im-leben*. Despite the significance of these human activities and their respective tools indicated above, early 19^{th} and 20^{th} centuries' teaching and learning theories have largely focused on the dialectics of Pavlovian stimulus and response theory (McSweeney & Murphy, 2014) in pedagogical practices (Daniels, 2001; Lee & Roth, 2007). The central thesis of Pavlovian theories centered on the notion that learning depends on human response to stimuli (externally or internally). This became the dominant educational theory and became definitive for policy formulation across the world. However, Vygotsky raised some concerns about the "atomistic and functional modes of analysis" that seem to delineate personal and social experiences and needs of the individual. He postulated the notion that knowledge was a social construction of society in stark contrast to cognate theories pontificated by Pavlovian school of thought. Vygotsky in pertinent part reiterated the well documented thesis that human beings engage in social and individual activities at both the intellectual and importantly at the social interactive levels through activity systems in their respective cultures. These *activities* are intentionally planned and purposeful in contradistinction to a response to a stimulus. As Lee & Roth (2007) pointed out, "the term activity is not to be equated with relatively brief events with definite beginning and end points but are evolving, complex structures of mediated and collective human agency" (p.198). Human *activities* are mediated by tools to create meaning and purpose and thus the outcome of these are evident in the social construction and evolution of knowledge. Hence the emergence of the social constructivist's theory in education. Indeed, Vygotsky postulated (towards the latter part of his life) that human activity mediated by tools are essential for teaching and learning (Daniels, 2001; Engeström, 2007; Kaptelinin & Nardi, 2017; Vygotsky, 1987). Human beings make meaning out of the tools and technologies they encounter to engage in meaningful activities. And this approach has become known as "Activity Theory" (AT) or as in the words of other scholars (Hasan & Kazlauskas, 2014), "Cultural-Historical Activity Theory" (CHAT). As Hasan and Kazlauskas (2014) poignantly indicated activity theory provides us a lens to perceive or human activities mediated by tools or contemporary technology as applicable to teaching and learning. There is no doubt that technology remains central to human activity in fields like agriculture, commerce, architecture, medicine, and education. Some proponents of activity theory (Blin & Munroe, 2007) believe that "activities are collective and motivated by the need to transform an object, which can be material or ideal (e.g. a problem or idea), into desired outcomes" (p.477).

2.2 Activity Theory: A Description

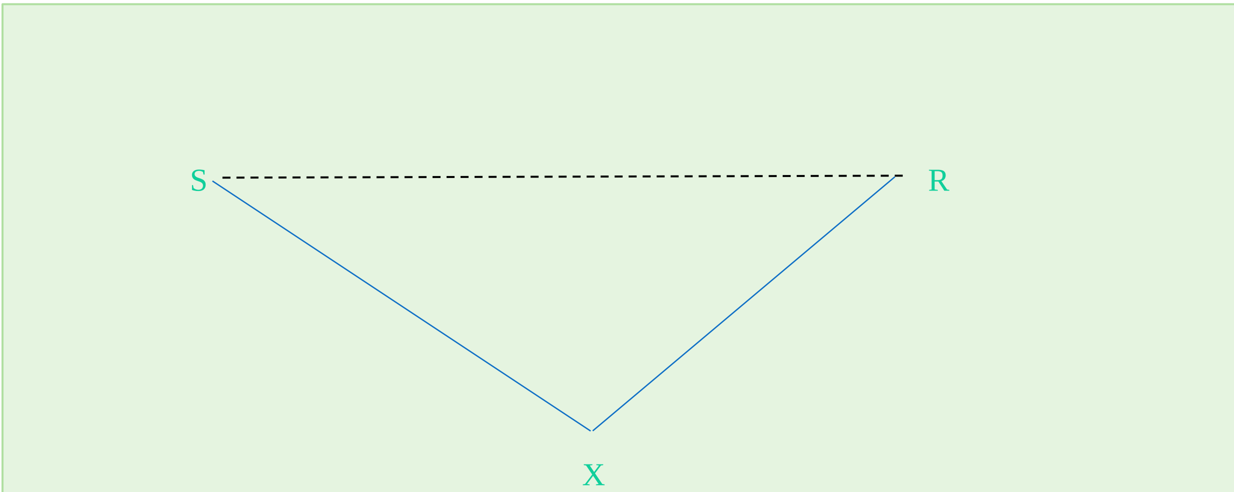
As indicated above, a corpus of educational research exists on the notion of how teaching and learning occurs across the lifespan (Engeström, 2007). Some have been concerned about the roles of human cognition in terms of cognitive sciences while others have examined how teaching and learning remain a social construct rather than an a priori cognitive activity (Alvarez, 2005; Daniels, 2001; Emdin, 2014; Engeström, 2007, 2009; Vygotsky, 1978). One strand of the social construction of knowledge theories focuses on the significance and roles of culture and how technology (Bippert,2019; Blin & Munroe, 2007; Engeström, 2007; Kuutti, 1996) shapes educational practices, especially science education. As indicated briefly above, Vygotsky was repugnant at the dominant cognitive theories propounded by Pavlov and other luminaries of educational theories. He theorized that human beings are social beings who actively construct knowledge including science through purposeful activities. These activities are physical and physiological. Human beings use tools and artifacts in the attainment of goals of knowledge construction by participating in desirable physio-physical activities in their social contexts. The emergence of 21st technology especially artificial intelligent systems have also shaped the discourses on human activity theory as applicable to education. As Kaptelinin and Nardi (2017) pointed out in a recent paper,

> A number of researchers, especially in Scandinavia and the United States, pointed out that by framing human–technology interaction within a larger context of purposeful human activities, the theory makes it possible to reach a deeper understanding of technology and its meaning for people. (p. 3)

Thus, human activity is "…the dialectic relationship between subject and object" -who is doing what; for what purpose (Vygotsky, 1978). As one of the pioneers (Engeström, 1996) of the theory pointed out, Vygotsky (1920-1930) was responsible for the *first generation* of activity theory. He postulated the concepts of mediation in human activity and learning known as "…the triangular model in which the conditioned direct connection (Figure 2) between stimulus (S) and response (R) was transcended by 'a complex, mediated act'. The "mediational" means of human activity was under the aegis of "tools" such as artifacts, machines, architecture, gesture, among others. The "activity triangle" below illustrates these relationships thus:

Figure 2

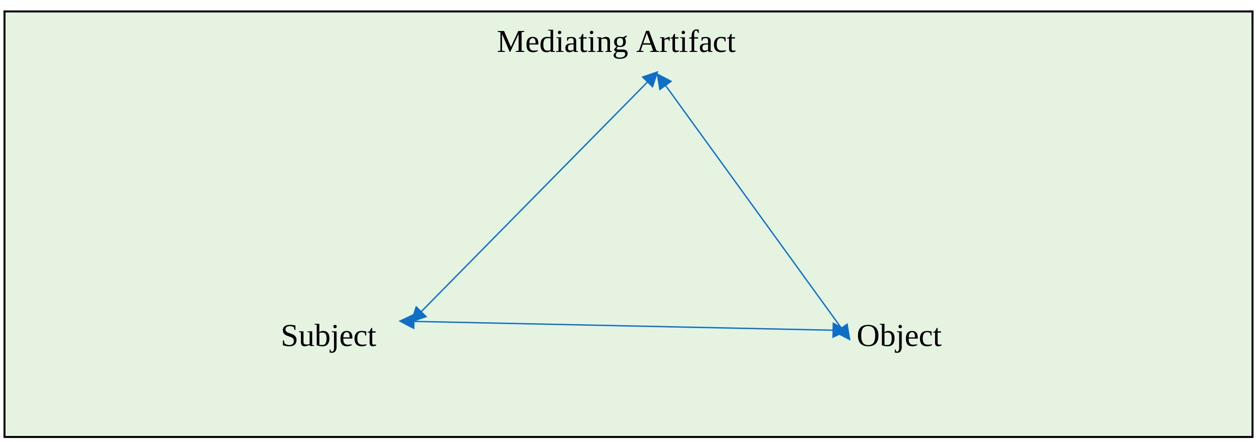
Model of Activity Theory



Note: This is a model of Vygotsky's stimulus(S) response (R) theory of activity mediated by a complex (X) mediating tool adapted from Engeström (1987)

Figure 3

First Generation Model of Activity System



Note: This is the triangular model of the first generation of activity theory

This initial model (Figure 2) was further expatiated into the *second generation* of activity theory (Leont'ev,1978) represented by *Figure 2*. Leont'ev pointed out that the first generation of activity theory (AT) was centered on individual human activity rather than the entire community. He saw this to be an inherent weakness in the theory. Proponents of the second generation AT postulates that human activity was concurrently a collective as well as an individual enterprise (Engeström, 2001). Individuals form the communities in which activities take place hence the concept of a 'collective activity system' as opposed to an exclusive individual activity model (Engeström, 2001). As Blin and Munro (2007) have succinctly noted,

> Within a Leontievian perspective, activities are collective and motivated by the need to transform an object, which can be material or ideal (e.g. a problem or idea), into desired outcomes. This motive gives sense and direction to actions or chains of actions, which are carried out by the subjects (individuals or groups) and which are oriented toward specific or finite goals. Actions, which are intentional and carried out through a series of routinised and automated operations, are mediated by tools, which can be material (e.g. books, computers, machinery, etc.) or psychological… (p.477)

There is an emerging quest to reformulate the third or the next generation of activity theory especially in the context of the emergence of artificial intelligent systems and digital technology as "tools" as applicable to teaching and learning STEM in the 21st century. As Engeström (2001) noted, "Cultural-historical activity theory has evolved through three generations of research. The emerging third generation of activity theory takes two interacting activity systems as its minimal unit of analysis, inviting us to focus research efforts on the challenges and possibilities of inter-organizational learning" (p.133) by focusing on four important questions: *1. Who are the subjects* *of learning? 2. Why do they learn? 3. What do they learn? 4. How do they learn?* These questions and a quagmire of others are significant for current discourses on the emergence of digital culture and the current generation of science reforms. This is because "in the context of learning, activity theory and its principle of contradiction can draw researcher's attention to important factors to consider when analyzing teaching and learning activity" (Ekundayo et al., 2012, p. 2). This implies the potentials of *contradictions* of previous and current technologies used in teaching and learning within educational practices due to

> the increasingly societal nature of work processes, their internal complexity and interconnectedness as well as their massive volumes in capital and capacity, are making it evident that, at least in periods of acute disturbance or intensive change, no one actually quite masters the work activity as a whole, though the control and planning of the whole is formally in the hands of the management. This creates something that may be called 'grey zones', areas of vacuum or 'no man's land', where initiative and determined action from practically any level of the corporate hierarchy may have unexpected effects. (Engeström, 1987, pp.113–114)

These contradictions promote "expansive learning" as it challenges educators and learners as well as stakeholders in education to explore some of these "grey areas" of technologies in tandem with current socio-cultural activities as mediated by artificial intelligence and digital worldview. As Engeström & Sannino (2010) noted "the process of expansive learning should be understood as construction and resolution of successively evolving contradictions" (p.7). Hence digital worldview including schools to become important *activity systems* mediated by artificial intelligent systems and digital technologies as tools in teaching and learning STEM education.

2:3 Summary and Perspectives

As indicated in the introduction to this dissertation, technology has been central among the earliest civilizations transforming them from agrarian, nomadic to semi and even sedentary societies. Post-industrial and contemporary worldviews are saturated with digital technologies. Indeed, the diffusion of AI and digital culture has launched contemporary society and social organizations towards a new technological feat. AI is found in many human activities and endeavors. Increasingly, educators have been paying meticulous attention to the extent to which AI and associated digital technologies are transforming educational activity systems. Herein Vygotskian AT and CHAT have become significant theoretical frameworks and templates to study technology as a tool in human activity. Several offshoots of the activity theory have emerged. Notable among these scholarships are Kuutti (1996) and Engeström (2001). The focus of this research is to collect qualitative data on AI/digital technology in educational activities for teachers with reference to Sphero Educ Robots teachers in their respective STEM educational spaces.

I have conducted this dissertation study through the theoretical frameworks of *activity theory*. The dissertation study research examined "… how communication, society and culture affect the evolving nature of activities over time" (Bippert, 2019, p.2) particularly digital technologies and in a digital multiculturism through CHAT. Indeed- "activity systems take shape and get transformed over lengthy periods of time. Their problems and potentials can only be understood against their own history" Engeström (2001, p.136). I believe AT theory offers a better lens to interrogate and study the significance of artificial intelligence and associated digital technologies in contemporary digital generation and digital culture. As Engeström (2001) pointed out, 'activity systems move through relatively long cycles of qualitative transformation" (p.137). These long cycles often inevitably generate dialectics or contradictions characterized by problems, distortions, and breakdowns; typically deemed "fuels for change and development within activity systems" (Ekundayo, 2012, p. 3). In this perspective, STEM have been examined as an *activity system* vis-à-vis digital technologies as tools in view of the research questions. Indeed, as Hasan and Kazlauskas (2014) have noted,

> in *Activity Theory*, the relationship between *subject* (human doer) and *object* (the thing being done) forms the core of an activity. The *object* of an activity encompasses the activity's *focus* and *purpose* while the *subject*, a person or group engaged in the activity, incorporates the subject's various motives. The outcomes of an activity can be the *intended* ones, but there can also be others that are *unintended.* (p. 9)

One of the goals in the dissertation research was on the examination of artificial intelligent systems as "tools" or cultural artifacts in the study of STEM. STEM in this context have been construed as an *activity system* mediated by artificial intelligent systems and digital technologies. As indicated in the introduction to the research, we are in a digitally driven world under the aegis of artificial intelligence. The first part of the research is to understand the nature and the caveat of what it means to be in a digital world (digital worldviews) as teachers. Worldviews shape our ideas, culture and decisional capacity and many choices people make in life. This worldview undoubtedly has significance for the current generation and the future of education, especially STEM. In addition, a digital worldview inundated with an avalanche of digital tools transcends every facet of life. I believe activity theory offers a better lens to inquire into the meaning of digital *tools* in the teaching and learning of STEM.

Currently, there is a proliferation of artificial intelligence technologies and apps purportedly designed and offered as potentially augmenting current teaching and educational practices. Some of these technologies are used to teach STEM such as *Sphero Educ*, Lego, while others such as Scrabble are used in the arts and linguistics. Some preliminary studies conducted by the inventors of the Sphero shows that these artificial intelligent tools have educational significance and potentially good in the teaching and learning of STEM, especially in a digital culture. There is a need to validate or offer an objective study of the application of these artificial intelligent systems and digital tools independent of the inventor's appraisal. Juxtaposing concerns raised by professional and academic bodies, the research examined how some of these technologies bolster and sustain STEM education in contemporary times as well as promoting rigor, motivation in the studying, and the assessment of the next generation of science disciplines. After all, education is a dynamic process in tandem with prevailing socio-technological and cultural experiences. As a product of current cultural phenomenon or artifact, digital technologies cannot be ignored as it is deeply rooted in the very fabric of society. At the threshold of the *Next Generation of Science Standards* (NGSS) in the USA, digital technologies will constitute a force to reckon with in promoting the interdisciplinary nature of the sciences (herein STEM) and the preparation of the next generation of scientists and the skills required to succeed after school. The current and next generation of citizens require adequate education and training of technologies needed for their respective profession as well as their daily life. As professional participants in our educational activity systems, it is imperative to prepare and equip educators with tools and skills for the next generation marked with a digital worldview. At the epicenter of this study has been an examination of teacher's perceptions of, and experiences with these novel artificial intelligent systems and emergent digital technologies as they relate to the various domains of their profession and STEM activities in their respective classrooms.

Chapter 3: Methodology

3:0 Introductory Comment

The proliferation and applications of artificial intelligent systems are observable and experienced in many parts of our lives. These include education, data science, statistics, commerce, security, and a concatenation of others. The impact of AIS and digital technologies has generated significant scholarship requiring further research of interest especially in the arena of STEM. That AIS and digital technology has created a digital culture of significance to education is uncontestable. Within this culture are digital natives and digital immigrants. The former deemed students born during the digital era and who exhibit unique characteristics and the latter encapsulates those born earlier or prior to the 1990s who by coincidence may constitute the cohorts of STEM educators. While some scholars claim that digital immigrants are averse to AIS and digital technologies (Cuban, 2001; Prensky, 2001), other scholars such as Bock (1985) believe that some teachers are open to using these technologies in their respective classrooms. I have noted the prospects of the AIS and digital technologies on the STEM educational landscape at the K-12 levels. AIS holds significant prospects for the advancement of STEM scholarship especially in the new synergies towards the *New Generation of Science Standards* in a digital world. I have inquired into the use of AIS in STEM classrooms in this dissertation study. This dissertation approached AIS in STEM classrooms through a qualitative method of research which according to Creswell (2013) uses,

> …theoretical frameworks that inform the study of research problems addressing the meaning individuals or groups ascribe to a social or human problem. To study this problem, qualitative researchers use an emerging qualitative approach to inquiry, the collection of data in a natural setting sensitive to the people and

> places under study, and data analysis that is both inductive and deductive and establishes patterns or themes. The final written report or presentation includes the voices of participants, the reflexivity of the researcher, a complex description and interpretation of the problem, and its contribution to the literature or a call for change. (p.44)

As Creswell (2013) correctly noted, a qualitative research begins with some assumptions and theoretical frameworks. This dissertation study has been informed by the cultural historical activity theory (CHAT) or activity theory generally consistent with social constructivism in its broader sense. I concur with these words of Creswell that this theoretical concepts and methodology will "… inform the study of [the] research problems" (p.44) of artificial intelligent systems and digital technology in STEM classrooms. In view of the above, I have detailed the methods including research designs, instrument for data collection, types of data, data analysis tools and approaches on the dissertation topic, *Exploring the use of artificial intelligent systems in STEM classrooms*.

3.2 Type and a Brief Description of Methodology

This is a *Qualitative Study* (Creswell, 2013, 2018) designed to explore the advent of artificial intelligence and associated digital culture on STEM education. A qualitative research is an important method of inquiry including data generation, analysis, pictorial representations, through several theoretical/conceptual frameworks of choice into a research question (Cassell & Symon, 2004; Creswell, 2018; Hennink et al., 2020; Wolcott, 1994). In the context of the research topic, researchers are privy about the use of AIS in classrooms in teaching STEM education. Since research participants were educators using Sphero educational robots and applications, the dissertation questions have been carefully crafted to offer them opportunities of reflection on their use of AIS in their respective STEM classroom activities. Thus, the study explored their experiences and practices of these technologies in the survey sent to them. Participants responses and data generated within the "natural settings" of their STEM classrooms were represented in the qualitative data in this chapter. The data was analyzed and specific theme/s or concepts for further study and analysis through the theoretical framework of activity with significance for pedagogy are reported in this chapter.

I have analyzed the dissertation data on the use of the Sphero robots in STEM classrooms from the perspectives of teachers using AIS. The study examined the pedagogical practices in STEM classrooms involving the use of AIS and digital technologies through the framework of activity theory. Which methods will AIS optimize in the STEM classroom and why? To what extent does AIS generate creativity, originality of thought and the recognition of the cultural diversities in a digital cultural classroom? In view of the above, the study focused on two *research questions*, namely:

I. *Artificial intelligent systems* and *digital technologies* have been applied in STEM educational domains (content, pedagogy, student learning, assessment). How does the application of artificial intelligent systems impact pedagogy *in STEM educational activities*?

Sub-questions:

a. What is the significance of AI technologies (for example Sphero) as pedagogical tools in STEM educational activities?
b. How did you integrate AIS (such as Sphero Educ Robot) into your STEM program?
c. What were your reasons in your choice and application of AIS (Sphero Educ Robots) in your STEM educational activities?
d. Has the use of artificial intelligent system and digital technology made STEM educational activities easier or more challenging?

e. How would you describe students' responses to the introduction and pedagogical application of artificial intelligent systems into their respective STEM educational activities?

II. There is an assumption that digital technology is transforming contemporary society in every facet. How does AIS tell us about how digital technology impacts STEM pedagogy?

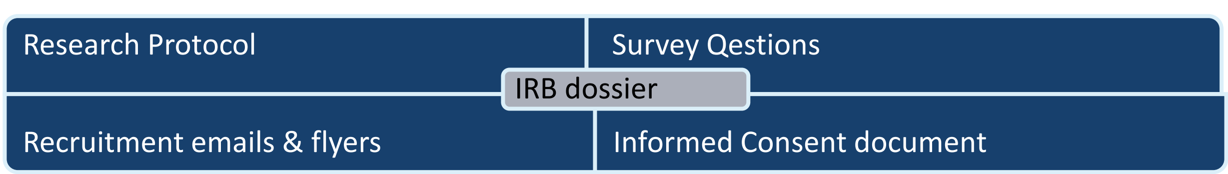
These questions constituted the guiding principles *ab initio* for the choice of data instrument such as the open-ended survey questionnaire, qualitative data analytical tools, theoretical framework as well as the final report and recommendations of this study.

3:3 Pre-Data Collection Phase: IRB approval and Site Selection

The research plan was initially presented to the dissertation committee during a data hearing in the Fall 2019. Once the research plan was approved (with minor corrections and recommendations), I contacted Teachers College Institutional Review Board ostensibly to obtain approval for the research. The dissertation research sponsor reviewed the above documents and approved the research dossier. The researcher electronically submitted the following documents in Spring 2020 to the IRB.

Figure 4

IRB Application Dossier



Note: All documentations (Figure 4) were approved by the research sponsor prior to submission to the IRB final reviews and approval.

These documents were designed in conformity with Federal, State, and local policies and norms as well as research ethics guiding principles involving human subjects. In these documents

(Appendix A), I have detailed the entire progressions of pre-data and data collection, storage, and security of the data, who has access and how the data was used. Data from respondents were stored on a personal database not connected to the internet as well as on Teachers College drive with password protection and encryption software. In addition, respondents' names were automatically deleted during the survey submissions in Qualtrics. The data is deemed anonymous. Any potential traces of identifying data with respondents have been deleted and pseudonyms used in contexts where researcher quoted survey responses in the final dissertation report. In addition, *Informed Consent* was obtained from each participant voluntarily. In brief, these issues have been presented and discussed with both researcher's sponsor and Teachers College IRB.

Teachers College IRB approved the Protocol (#20-187) under the aegis of ***Expedited Review*** *on 02/13/2020: Category (7) Research on individual or group characteristics or behavior*. After the approval, the educators who participated were identified as those using the Sphero robots listed on the Sphero educational and respective school districts webpages. E-mails were sent to the prospective participants based on their contact information listed on their school websites. In addition, e-mails were sent to the New York STEM educators association. After the initial responses, a list was compiled of prospective participants (32), who expressed interests in the research study. Those who did not want to participate were excluded from the initial list. From this list, *purposeful sampling* was used to identify participants from among the prospective STEM teachers. It should be noted that participants are residents across the United States (Texas, California, Florida, Maine, Vermont, New Jersey, New York). These participants constituted a cohort of STEM educators currently integrating some forms of AI/digital technologies at their respective Pre-K 12 schools. Since Sphero Educ robots have become popular in many K-12 schools in the USA and across the world, researcher narrowed the pool of participants to teachers of STEM proficient in the use of this technology. Participants have earned an undergraduate degree in STEM, at least five years in good professional standing including local licensures, certified as an AIS educator with at least five years of teaching experience. During the pre-data phase of the research, prospective participants with the above criteria were contacted. Some of the educators indicated that because they were certified by the Sphero and other AIS corporations, they wanted researcher to seek for permission from these entities to participate. Researcher assured them that the survey was anonymous, web-based and their individual data or any information linked to them were not going to be included in the final report. Based on this, the *Informed Consent* form was updated to ensure that their participation was both voluntary and completely anonymous.

3.4 Types of Evidence Gathered

As noted earlier, this is a qualitative study (Creswell, 2018). Several methods coterminous with qualitative research methodologies exist. I designed open-ended survey questions and uploaded them in Qualtrics – a qualitative research tool and software approved by the IRB. The survey was e-mailed to the participants. Other sources of data include archival such as sample lesson notes and training manual for Sphero educators that were referenced in the research data dossier.

It is important to note that six (6) out of the twenty (32) prospective participants participated in the survey. The initial projections were at least five (5) respondents. It is worth noting that one respondent declined the survey after signing the informed consent because the open-ended questions were inundating. The same participant expressed optimism for the "questionnaire" type of data instrument (albeit closed or structured research questions) as an option to participate in the research. Each participant completed the *Informed Consent* approved by the IRB. The surveys were administered, and the evidence was collected and organized initially into a Word document. Using the Macros functions in Word, the primary evidence was textually re-organized into a single aggregated file and labeled for further analysis. This evidence was then recorded into Word documents in Microsoft Macros and later into the Dedoose software suite for further analysis in view of the research protocol. The codes, memos, and notes emerging from the primary data analysis were used to identify core themes to formulate theories of significance.

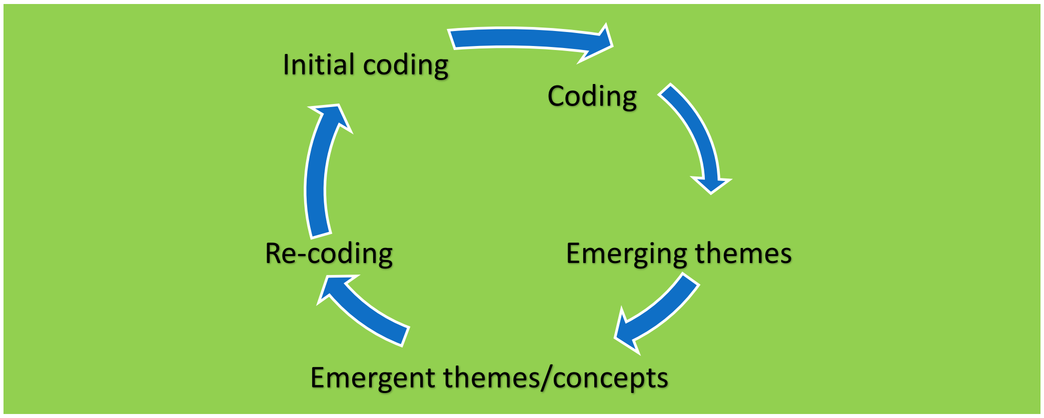
3:5 Analysis of the Evidence

Analysis of the qualitative evidence is at the fulcrum of qualitative research in science educational scholarship (Bazeley, 2003; Cassell & Symon, 2004; Charmaz, 2006; Creswell, 2018; Grbich, 2003; Hennink et al., 2020; Kuckartz, 2014; Richardson & Pierre, 2005; Wolcott, 1994). Evidence analysis is complex and sometimes deemed a minefield of uncertainty requiring meticulous attention and scholarly prudence. Indeed, analyzing such qualitative evidence does not ipso facto follow a straight track despite the popularity of applying codes to primary evidence to generate themes/concepts as used in qualitative research. In view of the significance of evidence to the scholarship on artificial intelligent systems and STEM education, this dissertation study analyzed the primary evidence in view of prevailing qualitative research practices to help ground themes as theories cognizance of the framework of the research.

In view of these, during the analysis of evidence, I followed an approximately cyclical procedure of coding, re-coding, thematic analysis and sometimes harking back to the procedure cyclically. This approach is illustrated below.

Figure 5

Data Analysis Process



Note: This describes the cyclical nature of the data analysis process from pre-coding to the emergence of themes

The first stage of the analysis entailed a meticulous organization of the text (Bazeley, 2013; Kuckartz, 2014) or the primary evidence that was collected. Because the survey questions (open) required free responses, participants' responses in terms of diction, font types and size, and textual organization differed from one another. To ensure uniformity and consistency, the primary evidence from each respondent was carefully collected accordingly in tandem with each question cluster. For example, all responses for question number one were collected and aggregated into one paragraph and all original or primary texts were retained. In situations where a respondent indicated "NA" (not applicable) and other inexplicable words such as "ba" were extrapolated from the final primary evidence as these constituted a qualitative data noise of no significance. Furthermore, the survey data was merged into one single Word document and saved as a file on the computer as a ***Data Transcript.*** The next stage was to create a *Macros* enabled document, so I followed this procedure:

I. I double clicked on the word document, *Data Transcript*

II. On the home page, I clicked on the *options* tab and I looked for the *Trust Center* and then I opened the *Trust Center Settings*

III. At the *Trust Center Settings*, I clicked on the *Enable Macros* and then returned to the main ***Data Transcript.*** At this stage, the document has been macros enabled.

IV. I clicked on the Control + Alt buttons ostensibly to highlight the text in the *Data Transcript*

V. I then clicked on the Control + C buttons which copied the entire *text* from the *Data Transcript* document. Then clicking on the paste tab (text only option), the data was transferred into a new macro-enabled Word document. This process copied only the text and excluded any graphics, special formatting, different fonts and merged all the transcript data as one file.

VI. I then clicked on the *view* and clicked on the Macros icons and *Record Macros*. The Macros functions appeared at this point. I then clicked on the *run* tab. This converted the survey data into a macros document. The macros enabled document appeared and I saved this document with a new name, *Qualtrics Data*. At this stage, the data was ready for coding and analysis. As a back-up plan, the document was also converted into a portable document format (pdf) and saved with a password on the same computer.

Coding in Dedoose

a. I then logged into the Dedoose software suite on my desktop. At the home page, I clicked on *Projects* and created a portfolio and named it under the caption of the research topic.

b. Under *Actions* tab in Dedoose, *Load* appears so I clicked on it which opens the Project Topic tab with the options of “Import” and “Export”. Clicking on the Import tab, Dedoose software suite opened my computer and I looked for the macros enabled document, *Qualtrics Data* and uploaded the document. This transferred the entire survey text into the Dedoose software suite for data analysis with no graphics.

c. To ensure security in Dedoose, I clicked on the options for encryption and created an additional password which automatically encrypted the entire project. This ostensibly conferred advance security and protection for the survey data. At this point, the document was deemed ready for coding and analysis in Dedoose. I describe this phase as the **Pre-coding Phase.**

3:6 Coding Phase

Secondly, after the **Pre-coding Phase,** I opened the survey data now in the Dedoose software suite in the Home page and explored the *Code* tab. This opened and displayed the entire survey data as a textual document with the *Code function* to the right. After the above, I began the ***Coding Phase*** by meticulously reading, textually analyzing the primary data in view of the research questions and the theoretical framework of the dissertation study. After reading the text twice, I decided then to start the coding at the third reading. After each line, a sentence or paragraph, I created codes by clicking on the Code tab in the Dedoose software suite and applied the *Add Root Code* commands. I followed this procedure till the end of the document. In the second re-coding procedure, I simply right clicked on the main document for the *Add Code* command to be effected. This allowed me to simply link new phrases, sentences, or text to an existing code. It is important to note that this phase is rather cyclical. This is because after assigning codes, I re-analyzed the primary data at least three times until a point of *textual saturation* (Birks & Mills, 2015; Fusch & Ness, 2015; Glaser & Straus, 1967; Olshansky, 2015; Saunders et al., 2018) was attained; or as in the words of Hennink et al. (2017) “no additional issues are identified and the codebook begins to stabilize” (p. 4). In addition, some of the codes were so similar for example, project-based and problem-based, so I simply merged them by clicking on the *Add Root Codes commands* and made the desirable code “primary” and scrolled down to highlight the “secondary code" options. Once the secondary code appeared, I single clicked on the *merge* button, which automatically deleted the secondary code and retained the primary code. This process helped coalesce similar or identical codes of themes in the text. At this phase, *twenty codes* emerged with corresponding memos or notes. I then exported the entire document (with codes and notes/memos) into the desktop macros-enabled word file and saved it as a new document-*Survey Data2*. I then opened the document and extracted each Code and Memo for further analysis and study using the *Sticky Note* function. Under each code, I wrote brief snippets or memos to explain or link the texts. These codes were thematically identified and were re-coded and out of which twelve themes/concepts emerged. The final themes emerging from the primary data (in sticky notes) constituted the final themes upon which my theoretical framework was grounded.

3:7 Preliminary Conclusions

In this chapter, I have described and detailed the research design including survey instrument, the data collected and data analysis such as coding. The findings/results of this primary data analyzed are discussed in the next chapter of this dissertation study.

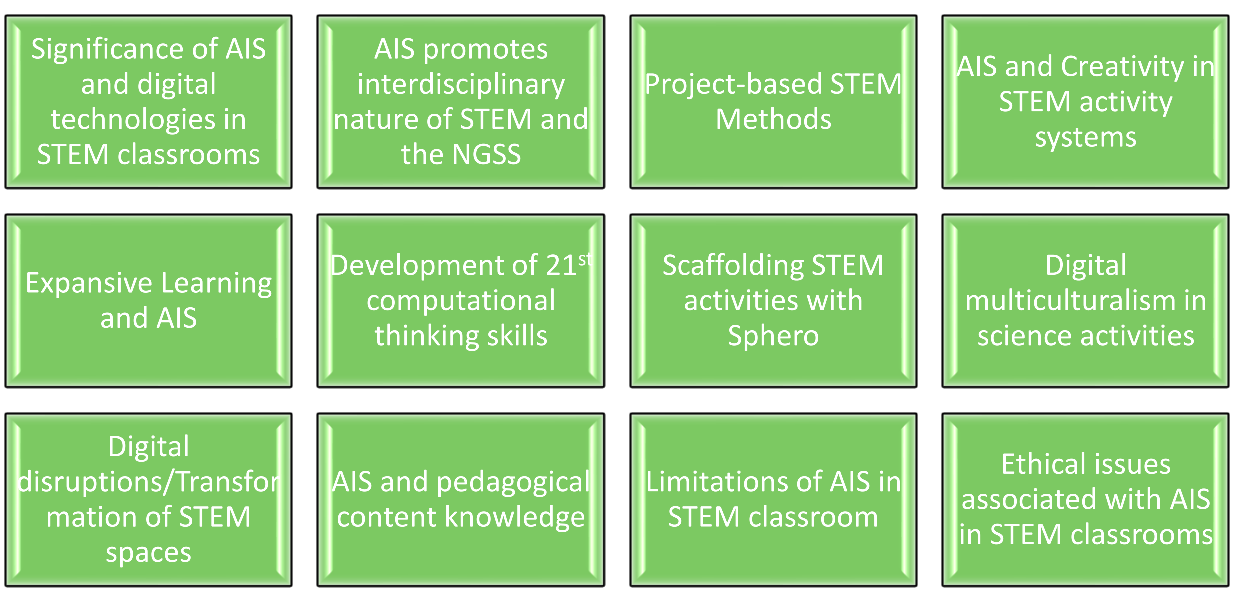
Chapter 4: Findings

4:1 Introductory Comment

In the preceding chapter of this dissertation research, I have outlined and described my research methodology including the instrument for data collection, tools for data analysis procedure using Dedoose software suite and micro-enabled word document. Through meticulous analysis of the data, over twenty themes emerged initially. These were assigned codes, snippets as well as memos linked in the Dedoose software suite. This approach helped me to identify clusters of themes and key concepts that overlapped. I conducted further analysis of the themes and consolidated them into the following twelve emerging themes (Figure 6). I considered the similarities of these themes/concepts, the rate of their recurrence (albeit textual saturation) and the broader context of the research topic and theoretical framework. These themes are tabulated below.

Figure 6

Emerging Themes



Note: This figure illustrates the twelve emergent themes from the qualitative data analyzed.

Because of the stark similarity of some of the themes, I continued coding until a point of *textual saturation* was attained. In other words, no new themes or concepts emerged from the additional textual analysis or coding process. This was construed to be an indication that the themes identified reflected the available empirical data to inform the research study. Accordingly, these twelve *emergent themes* from the primary data were then coalesced upon further re-coding and synthesized into specific but overarching *themes* for further analysis in this chapter. From these emerging themes (Figure 6), I selected seven (Figure 7) for further study and analysis and in anticipation of discussions in view of the dissertation topic and the central questions of the study. The significance of these themes to STEM classrooms will constitute the main findings of this dissertation study to be further examined in this chapter.

Figure 7

Major Themes

Note: This figure encapsulates the seven themes analyzed in this chapter.

4:2 Analysis of Research: Evidence and Exposé

One of the themes stemming from the survey instrument data is the significance of the artificial intelligent systems and digital technologies in STEM classrooms. There seems to be a consensus among respondents about the importance of AIS in STEM classrooms activities. Thus, at the beginning of the data analysis (pre-coding and coding phases), it was an easily identifiable theme in almost all the categories used in clustering or grouping the primary data during coding. That AIS have prospects for STEM is undeniable to all respondents in their respective STEM classrooms at the K-12 level. Indeed, the first research question was designed categorically inquiring into the significance of the artificial intelligent systems and digital technologies to the STEM classroom. Respondents agreed that there is a digital culture concomitant with technologies such as artificial intelligent systems unlike previous generations. This imposes a responsibility on STEM educators to be competent and skillful in these emerging technologies to be efficient teachers.

There is however a divergent twist to the significance of AIS in the STEM classroom. Some respondents believed that AIS have pedagogical significance to current STEM classrooms while others see it in the future. The first sub-theme is that AIS ***currently*** has significance for students and by extension STEM classrooms in real time. In probing this further, I examined the survey data again particularly the key concepts and words of respondents after the coding phase. Respondents linked AIS to some domains of STEM classroom activities such as learning. That is to say, the AIS such as the Sphero is deemed an instrument or a tool to augment STEM classrooms learning activities. AIS are perceived as augmenting traditional approaches to teaching and learning STEM. As one respondent, Johnson indicated in the data instrument "*I think the technology of Sphero is important for students to learn…"* while Nancy posited that *"the Sphero*

Robot gives students an opportunity to learn about robotics in a simple format and also about sensors". Juxtaposing these views, one can extrapolate one theme about the importance of the AIS technologies in STEM classrooms. It is important to note that STEM educators who provide these AIS to their students are invariably helping them learn coding, robotics, sensor engineering and other novel STEM concepts and skills reflective of current trends in educational policies and practices. This is also significant especially at the threshold of rolling out the NGSS in the United States educational sector. Even though these are not *ipso facto* Robotic and Coding specific STEM courses, nonetheless there is a convergence of skills and concepts relevant for consideration in contemporary classrooms. Thus, there is evidence that AIS and digital technologies such as Sphero robots have educational use or significance in STEM classrooms. The research has given these STEM teachers opportunities to offer their reflections on their observations about the nature and use of these tools in the domains of pedagogical practices.

Furthermore, respondents believe that the use of AIS in STEM classrooms are linked to prevailing community practices or applications. Teaching and learning occurs within specific socio-cultural contexts and times. Education is deemed relevant to the community if teaching and learning reflects standards and practices of prevailing socioeconomic caveats. As I have discussed extensively in the second chapter of this dissertation study, almost every sphere of contemporary life is saturated with digital technologies. The history of education has shown that the applications of technologies has often transformed and prepared educators to teach the prevailing skills and knowledge relevant to socioeconomic ventures, industry, security, architecture, agriculture and among others. Education ultimately served as a bridge between the "real world" and the "classroom" or world culture and school culture so that students are contemporaneously prepared with skills and relevant knowledge. These views and assumptions have been echoed by research participants in their response to the survey. There is no doubt that AIS are also found in the real world of the larger community. AIS and digital technologies are not antiquated but real and perhaps reflective of *"…how they can be used in the real world"* (Nancy). By inference, the *real world* implies that the AIS technologies are of some significance to contemporary communities both within educational sectors as well as the communities in which students, educators and parents live. This points to the absolute link between STEM classrooms and the *real world* in terms of the application of AIS and digital technologies in teaching. In brief, digital worldviews are inexplicably exemplified by the presence and applications of AIS and technologies in STEM classrooms at the K-12 level, especially in the USA.

In addition, the application of AIS in STEM classrooms and educational practices is a further indication of how these are used to prepare or educate *current digital students* to reflect their world. Thus, STEM teachers directly create a real world of scientific practices whenever they incorporate AIS in teaching STEM. After all, there is a consensus that we are in a digital culture precipitated with many forms of artificial intelligent systems and digital technologies. This sentiment was captivatingly expressed in the words of another respondent, DeMark thus, *"students will be using micro-controllers and other digital tech to design and create solutions to problems they see in the world. This mirrors what is going on in the real world".* Undoubtedly, this is a paradigm shift of a contemporary STEM classroom in comparison with pre-digital natives' educational spaces and unique experiences. Education reflects prevailing worldviews and socio-cultural experiences of students, educators, and the larger social community. Availing AIS in STEM classrooms naturally aligns or merges digital natives' experiences with the 'real world' where their worldviews and skills converge in the STEM classrooms as they use AIS to learn. The use of AIS undoubtedly is significant and guarantees that STEM classrooms reflect prevailing digital worlds and experiences in advancing teaching and learning. In brief, there is a gradual diffusion or applications of these AIS to align with good pedagogical practices towards the attainment of educational objectives in STEM classrooms. This is a new phenomenon and approach to teaching STEM construed as a cultural activity.

AIS is also significant in the *future* for STEM educational activities and school culture. After all, technologies are dynamic, and they change rapidly in shaping the prospects of current and future generations. In reviewing the literature, I noted that AIS has always been in existence conceptually and later as a reality especially in the latter part of the 20^{th} and 21^{st} centuries. These technologies shape the current and future generations by improving or advancing previous and prevailing ones. Research participants have offered their reflections about the changing trends in the digital era. They have availed themselves for the professional opportunities to be formally trained and prepared throughout the certification process either as Google STEM educators or Sphero STEM teachers, among others. One of the respondents, Arinze suggests that “true AI systems will become important in the future to ready students for future careers”. Here the significance of AIS is seen through the aperture of the *future* of STEM educational activities. In other words, some of the respondents felt that AIS and digital technologies are at the *emergent phases* and accordingly do not agree completely with the presumption that the Sphero robots and applications are truly AIS capable of exhibiting autonomous decisional capacities. This view is important as it hinges on the research topic: Exploring the use of AIS in STEM classrooms. Though the application of AIS and digital technologies in STEM classrooms at the K-12 levels in the USA may seem to be at the exploratory stages, nevertheless it is diffusing rapidly unlike other technologies. For instance, the telephone invented in the 19^{th} century (1876-Alexander Bell) was used by relatively few people until 1998 when the technology reached almost every household in the millions of phone lines data recorded in the USA. That is, it took over a century to reach almost every household in the USA. By the mid-1970s, diverse networks were connected to develop the internet. Unlike the telephone, within a relatively short time, the internet reached many millions of people all over the world by the late 1990s, while the cell or mobile phones emerged in the 1990s and rapidly became popular and reached a significant number of people across the globe in a relatively short period.

Currently, digital technologies and AIS are changing rapidly with great prospects for contemporary culture in STEM educational activities. Indeed, as DeMark further noted in his response to the survey "We are just beginning to implement learning about AI and right now we reflect the infancy of AI in the real world". Some key words and concepts such as *just beginning*, *implement* and *the infancy* are of particular significance to the research. It is true that AIS are just *beginning* to diffuse into the educational sector especially STEM classrooms. There is no doubt that the different AIS technologies are emerging, changing, and impacting society at a faster pace than the telephone technologies reached and impacted the world. AIS and digital technologies are combinatorial, scalable, and easily adaptable to suite a plethora of educational situations. These require continuous apprises, adaptations, and implementations as these technologies are applied to STEM classrooms. It is thus refreshing to note from the data that participants are opened and incorporating these technologies into the core constituents of their pedagogical domains especially in STEM classrooms even at these beginning phases of the impact of AIS. After all, as the saying goes, *tempora mutantur et nos mutamur* (the times are changing, and we change in them). I believe this openness will lay the foundations for a robust technological architecture for the current and future generation in advancing the teaching of STEM. So, to some extent DeMark may be accurate in the assumption that "we are just at the beginning" and at the rudimentary stages in developing

AIS of pedagogical significance. The inventor of Jill Watson, Prof. Goel observed in a recent interview to the *Business Insider, "to capture the full scope of what a human TA does, we're not months away or years away. We're decades, maybe centuries away, at least in my estimation," Goel says. "None of us (AI experts) thinks we're going to build a virtual teacher for 100 years or more"* (March 22, 2017). This is also a further confirmation that we are still at the budding stages towards the application of AI into our pedagogical practices in teaching and advancing STEM. Indeed, a cursory look at the technology seems to lend credence to this unique insight and perspective of the research participant given the prospects of the fifth generation (5G) of information technology and potential significance in obliterating current technologies and potentially paving ways for the next generations of AIS and digital technologies. Recently, an emerging technology company, ReadyAI has indicated they have developed an AIS "…curriculum [which] includes customizable AI lessons and a showcase event. Through this curriculum, students will know and be able to implement essential AI concepts, and create projects of how they can make our world better with AI" (2020). In view of these, it is imperative for STEM educators to incorporate these new technologies towards the creation of dynamic and relevant teaching and learning spaces reflective of prevailing digital worldviews and culture. In the context of an activity system, AIS and digital technologies create opportunities, teaching tools and symbols in STEM educational activities at the K-12 level. Thus, the Sphero app and cluster of technologies are "great to scaffold STEM lessons" as one respondent poignantly puts it. AIS and digital technologies cannot be overlooked given the ever-increasing prominence it is proffering in transforming pedagogical spaces, practices, and STEM educational activities. As we will discuss later in the next chapter, the proliferation of AIS is implicitly contributing to the scholarship on the theories of teaching-learning at the K-12 levels as applicable to STEM and other content domains. The current data extrapolated from the survey elucidates and forms a theoretical basis of pedagogical significance for STEM teachers and potentially for other content areas at the K-12 levels.

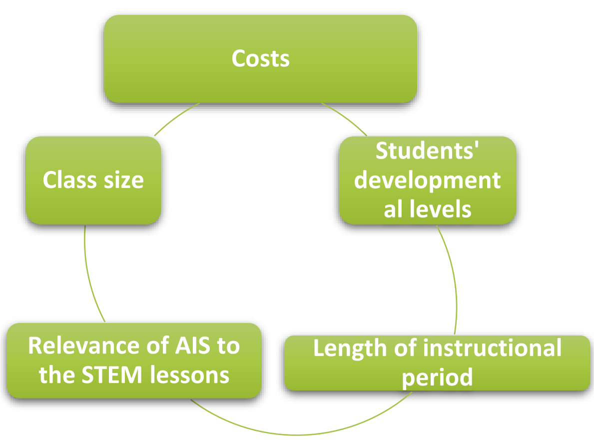
Secondly, there is a consensus that AIS and digital technologies are pervasive and have *created digital culture*. And as noted above, the pervasiveness of digital culture implies that STEM classroom reflects these changing trends or zeitgeists. While the primary data and initial textual analysis above shows unanimity on the significance of AIS and digital technologies to STEM education, respondents were divergent on factors influencing or determinant on the choice of these technologies. I asked research participants the following questions in the survey: *Describe some of the limitations of AIS (such as the Sphero Robots in your STEM educational program in your respective schools.* The diverse responses are significant to understanding the prevailing parochial digital school culture including the power dynamics involved in making decisions about pedagogical resources in STEM. Clearly, STEM educators are at the frontiers in making some of the important decisions about technological resources in their respective classrooms. This is a good indicator assuming the decisions are of educational relevance and timely. At the time of designing and collecting this dissertation data, not all K-12 schools have reliable communication technology- a key component of AIS and digital technologies. For example, Wireless Fidelity (WiFi) technology is a backbone of AIS technological architecture in educational spaces, especially classrooms. It creates the communications pathways for all AIS to be on the same platform during STEM lessons. Respondents believe that this is one of the main factors they considered in making their decisions about the type of technologies they selected for their respective STEM classrooms.

In addition, there is no national policy nor consensus among professional bodies as to the choice or type of AIS and digital technologies for STEM classrooms. While some school districts budget for or provide schools with these technologies, the review of the initial literature did not settle this lingering question on the factors STEM educators consider on their choice of AIS for STEM educational activities. Technology is not cheap especially as many are still at the "beginning" phases of innovation and development. Participants believe the costs of AIS and digital technologies also impacted their decisions.

In addition, respondents postulate that they were informed by class size on the choice of AIS technologies for STEM activities. Obviously, fewer technologies are procured if class size is small with inverse significance for costs of procurement. Undoubtedly, there are many forms of AIS and digital technologies of educational significance in the world. In fact, Sphero has diverse robots and applications for STEM classrooms. Some are suited for specific topics or kinds of lessons and grade levels. However, in choosing the Sphero robots and apps, respondent identified costs, class size, students' developmental levels, length of instructional period, and relevance of AIS to STEM lessons and activities as key factors in the selection process.

Figure 8

Educator's choice of AIS



Note: This illustrates factors influencing educator's choice of AIS technologies for their STEM classrooms.

Even though there is a proliferation of AIS of significance to STEM classrooms, the data from this study and the emergent theme shows that not all schools have access to these technologies. Educators seem to have the vested interests and authority to determine and ultimately choose which kinds or types of AIS they might use in their respective STEM classrooms. As such STEM teachers are unrestricted in the selection of AIS and applications in the STEM classrooms. Technology giants such as Apple, Facebook, Microsoft, LEGOs, Sphero among others have been instrumental and supportive in the provision of these AIS and training of STEM educators at selected Schools. As indicated pictorially above, some of the respondents indicated that cost is a decisive or determinant factor in selecting AIS for STEM classrooms. Obviously, this gives credence to the presumption that not all STEM classrooms and schools have equal access to these technologies. As such STEM educators consider budgetary allocations in procuring the Sphero robots applications and other allied AIS. A pre-survey and post survey data show that AIS may be deemed costly. For example, the Sphero robots and accessories cost $150 and above. As one respondent puts it "Sphero robot is very expensive, so we have relatively few (12). I therefore consider the class size and access to the robots." Hence providing AIS to every student in STEM classrooms can post budgetary challenges and especially in situations where some K-12 schools districts and leadership may be resistant or averse to digital culture. The issue of costs is not just limited to the initial procurement of these technologies but the long-term management as well. This includes, costs associated with storage, maintenance, updates (to software and sometimes the hardware), transport, security, and others. There is no doubt that AIS and digital technologies remain core components of contemporary life and school digital culture. It is hoped that as the demands for these technologies increase costs will dissipate for it to be made readily accessible for STEM educational activities.

The utility of the AIS and digital technologies are also important factors worth considering. Not all AIS are relevant to STEM classrooms and not all STEM classrooms are suitable to AIS and digital technologies. Thus, in choosing an AIS, the data from the survey suggests that STEM educators evaluate the utilitarian value of these AIS and technologies especially their applicability to their STEM classrooms, types of lessons, concepts being taught and their respective developmental standards, among others. As one respondent, Nancy rhetorically posited: *Does it meet standards and appropriate to students' developmental levels?* For example, the Sphero robots have many applications at various levels such as introductory coding, block, variable and logic features but it can also be used for other programming languages such as in JavaScript and Python. In an activity system, pedagogy is deemed relevant within the "zone of proximal development" (Vygotsky, 1978) hence respondents appear accurate about being guided by the *developmental levels* of their respective students prior to introducing AIS and digital technologies to their STEM classrooms. Micro Bit, LEGO, Sphero and other educational AIS corporations have created diverse technologies and programs coterminous with students age and development. Some are tailored to K1-6 while others are for high school students specifically. Due to technological flexibility and adaptations, AIS and digital technologies are easily customized and adapted for different developmental levels and content domains.

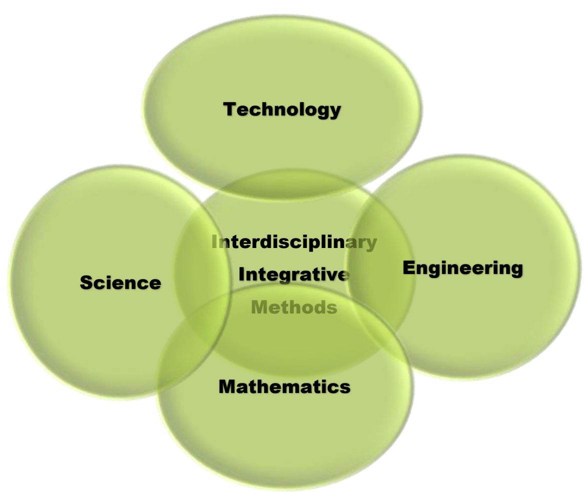
Also, class size or school population and length of instructional schedules have been identified as key factors in considering an AIS and digital technologies in STEM classrooms. Unlike other platforms such as Canvas, Google Classrooms, Google Jamboard, Sphero CST platforms/applications are readily accessible to many people hence their applicability to Massive Open Online Courses (MOOC). AIS are carefully engineered to suit specific STEM objectives and many lessons or topics. They are therefore costly and pose logistical restrictions or limitations by their designs and nature. Some of the respondents categorically alluded to that effect hence their choice of the Sphero robots and applications.

Thirdly, responses from the participants consistently identifies "project/problem-based methods" of applying AIS in teaching STEM. This theme is detectable throughout the responses from the survey. In analyzing the data, I tried consistently to review the expertise and background of the research subjects. It should be noted that they are all STEM educators of varying years of professional experiences and have been certified in the use of the Sphero robots and applications within the past five years. During the pre-survey phase, they have indicated that the shift in teaching STEM from the lecture and other ineffective methods to the project-based methods are student-centered, efficient, and impactful. The application of AIS and digital technology in the project-based method have been deemed a tidal wave of immense proportion in shifting and sustaining pedagogical practices and education in the contemporary STEM classrooms. This is reflected in the current primary data. To tease this concept out during the data collection phase, the first dissertation question and sub-questions were structured to elicit further information on this. As we noted above, the responses are tellingly insightful and perhaps requiring further probe beyond the scope and trajectory of this dissertation. It is however worth noting that the Sphero robot and the applications have incredible designs and technological features that are malleable and adaptable to myriads of project-based STEM activities. Indeed, as one of the respondents indicated, the Sphero "creates a new learning environment for STEM activity" and "it gives teachers a new platform from which they can scaffold learning about robotics and coding". STEM activities can be structured around the "learning environment" herein STEM classrooms. These new learning environments are digital platforms and architectures with distinct teaching and learning tools such as the Micro Bit, Google Jamboard, Sphero robots in advancing STEM. This also entails virtual STEM teaching and learning environments and relevant technological architectures. Educators can identify specific concepts, topics or learning objectives and structure lessons so learners could pursue these projects using the robots, features and functions of the apps. For example, as some of the respondents have indicated, they have used the Sphero project-based lessons through which learners had access to the robots to learn about concepts in programing, electricity, theories of light, acceleration and gravitational forces, quadratic equations and graphs, and many others. One of the points of departure is that this approach anchors and sustains learners' interests in STEM, develops their team building skills, helps them pose higher order questions and offer them the opportunities to inquire and demonstrate their independent research and other skills required of practitioners of science. In the next chapter of this dissertation, an in-depth reflection, and a case for the pedagogical significance of the project-based method vis-à-vis AIS and digital technologies in STEM classroom through the lens of the theoretical framework of activity theory will be brought to the fore in view of this insights from the primary data analysis.

Fourthly, according to the current dissertation survey data, AIS promotes interdisciplinary or integrative nature of STEM. This theme emerged throughout the data analysis phase. This theme or concept is critical as we are currently at the threshold of the introduction of the *Next Generation of Science Standards* and other science reforms across the nation. One of the pervasive theoretical bases for the NGSS is the interdisciplinary or integrative nature of STEM. But how does AIS promote this? What does the interdisciplinary nature of teaching and learning attempt to correct in STEM education in the country? At the literature review section on this dissertation research, it was noted that the teaching, learning and practice of science has undergone some developments over the decades in this century in the USA. This was reiterated during the pre-data phase of this dissertation study. Empirical evidence has shown that the luster and competitiveness of STEM education has dissipated in the USA. While the United States used to be a leading powerhouse of science and technological feats, several events including teaching methodologies might have contributed to the dwindling numbers of citizens not interested in pursuing STEM related scholarships to the chagrin of policy makers and educational authorities. Several papers and scholarships have identified the fact that STEM (broadly construed), mathematics, engineering, technology have been taught independently and in isolation of each other. K-12 level curricula have distinct courses in Science (Biology, Chemistry, Physics, Environmental, Earth Science), Technology, Engineering and Mathematics (Algebra, Geometry, Calculus, Statistics) just to mention a few. Whereas by nature and praxis, these scientific disciplines existed and share common features, cross-concepts among others hence the call for the interdisciplinary approach to teaching and learning STEM in contemporary classrooms. The presence and development of AIS and digital technologies such as the Sphero can promote this *interdisciplinary* approach (Figure 9) to teaching STEM.

Figure 9

Method of Teaching STEM



Note: This illustrates the integrative/interdisciplinary approach to teaching STEM

The current dissertation data gives credence to the integrative teaching of STEM with the use of artificial intelligent systems and digital technologies. One of the respondents, Nancy noted that the Sphero is “useful across [the] disciplines of STEM”. The key concepts here is “across disciplines of STEM.” This is ultimately a bold claim identifying Sphero as a pedagogical tool and platform in promoting and teaching STEM with a novel methodology. Indeed, STEM by nature is a conglomeration of four seeming distinct content areas. Many countries and schools of thoughts have approached teaching Science (Biological, Chemistry and Physical), Technology, Engineering and Mathematics as separate and independent subjects over many generations. However, there is a seemingly global consensus towards a more integrative approach to teaching STEM. This policy shift has undoubtedly permeated current K-12 STEM reforms efforts and educators have been intentional in embracing this apparent shift in policy and praxis. Respondents to the current study believe that AIS and digital technologies are consistent with this new trend in integrating STEM. This assertion is consistent with the proposition that artificial intelligent systems and digital technologies will create pathways towards the integrative and interdisciplinary approach to teaching STEM education. While the current data focuses on the Sphero users as an exemplar of AIS, it is plausible to apply this finding to STEM classrooms and allied educational spaces and contexts. In fact, there is an explicit connection to this assertion in the words of one of the respondents, DeMark thus:

> Sphero has many applications and diverse robots for STEM and in fact STEAM education. I have used the Sphero robot to teach “patterns” an important cross-concept in geometry, earth science, chemistry, physics. Students programmed the

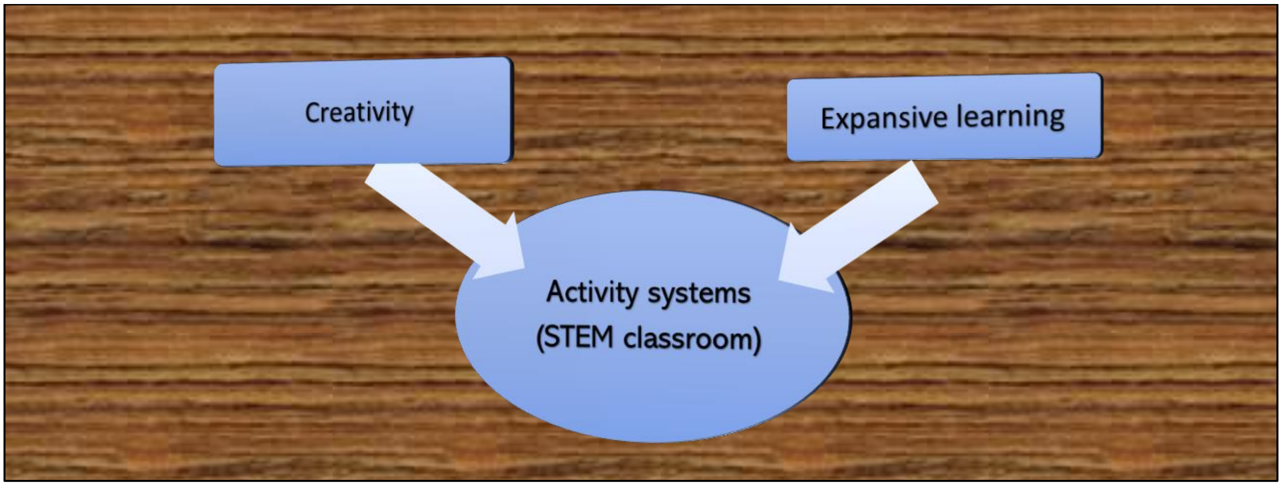
robots and colored them to create concentric circles in the class. This activity illustrates an integrative problem-based approach to STEM

The concept of pattern alluded above is a cross-concept/theme found in science, technology engineering and mathematics. It is fascinating that one artificial intelligent system and a cluster of digital technology has the intrinsic capacity to achieve this goal. It should be noted that the Sphero and the avalanche of AIS are not panacea to promoting interdisciplinary methods of teaching and learning STEM in the classroom per se. Nevertheless, the current study and empirical data seems to be a good pointer for further analyses and scholarship. It is hopeful that as educators embrace the new paradigm shifts in the teaching calisthenics of STEM, there is a concomitant consideration and application of culturally relevant and appropriate technological tools in the classrooms to achieving these goals.

Fifthly, artificial intelligent systems promote *creativity in STEM activity systems* and expansive learning in the classroom. These two themes have some veneer of truth but nonetheless are closely aligned conceptually requiring concurrent analysis. In the initial analysis of the data, the two concepts of "creativity" and "expansive" learning were assigned different codes. However, as these two concepts became emerging themes, I decided to re-examine the research questions as well as the data elicited in the light of the theoretical framework of this dissertation. The data shows that creativity/expansive learning are central to activity theoretical systems or cultural historical theory. One of the prominent proponents of the third generation of activity theory, Engstrom extensively suggested that technology is significant in generating creativity and promoting expansive learning within culture.

Figure 10

Creativity and Expansive Learning in Activity Systems



Note: This describes a confluence of creativity and expansive learning in a STEM classroom with an AIS and digital technology.

In addition, some AIS can be *combinatorial* with *re-programmable* features adaptable for an array of educational circumstances. For instance, the Sphero robots and apps are adaptable for teaching biology, physics, math, painting, architecture, computer science and others such as painting and linguistics. Students gain critical thinking and creativity skills thereby *expanding* their *learning* and obviously intellectual skills in STEM and as Nancy insightfully noted, "…it strengthens our pedagogy and results." AIS generates, transforms, and sustains creativity in learners if properly used in scaffolding STEM lessons in schools. I must stress however that the notion of creativity in the context of AIS in STEM classrooms are reflections and perspectives from teachers about students. I believe students views will have bolstered this assertion or claims by respondents. But obviously, that is beyond the scope of this dissertation as my intent has been about STEM teachers at the K-12.

Sixthly, there is a truism in the thesis that technology transforms society and way of doing things. Traces of these assertions have been identified as one of the emerging themes in this research data. However, there is empirical evidence to buttress the impact on STEM classrooms especially AIS and digital technologies. Of course, most AIS are constantly changing and there is evidence of diversities of these technologies in existence. A synthesis of the current data adduced above is consistent with the *transformation* caveats of the digital age marked with artificial intelligent systems in education. To tease out how AIS has transformed STEM classrooms, the survey posited an important open-ended question and participants shared their views as noted above. Research participants believe AIS and digital technologies such as the Sphero are transforming STEM classrooms and invariably sustaining digital culture. Some of the key areas in the data include teaching methods such as activity (project/problem based), the applications of Sphero robots and applications to teach STEM, the tacit creation of digital or virtual contents and labs to scaffold teaching and learning in the classroom among others. Some of the respondents have suggested that using AIS as assessment platforms as well as tools to review and measure student's performance and mastery of STEM content in real time and at the end of teaching or during other relevant educational activities. This is an important milestone and signifies a pathway from the traditional textbook, brick, and mortar approach to teaching STEM towards the creation of digital contents as well as innovative pedagogical practices. Fortuitously, it prepares both STEM teachers and learners to acquire critical computational and other digital skills needed to be relevant in the workforce and in the real world marked by artificial intelligent systems. In addition, the current data suggests that STEM educators change their demeanor and power dynamics in their respective classrooms. For example, Nancy indicated that the Sphero "…*helped me transform as an instructor to a facilitator"*. That is students in the STEM classroom become the active learners and participants of the teaching process partly due to the applications of AIS to scaffold learning in the STEM classroom. This theme is consistent throughout the coding process.

Another transformative nature of AIS is the unique skill of STEM educators. There is ample empirical evidence and data to the effect that teachers or educators' content and technological skills impact their teaching skills and invariably their students either positively or negatively. The digital era has created both opportunities for STEM educators as well as a crevasse for continual learning and acquisition of these new skills to remain professionally and culturally relevant and efficacious. Sphero educators have availed themselves to be formally trained and certified with important skills. Thus, the transformation of the STEM classroom has begun with their apt mastery of these skills and knowledge. As one of the respondents indicated, the training has "helped reinforce my limited coding skills and build those up a little. It provided a platform to scaffold instruction and helped…students" to participate in STEM. Another participant DeMark also suggested that "the Sphero certification training process gave me the opportunity to advance my digital skills such as coding and programming". In other words, STEM educators herein Sphero educators are building and developing critical digital skills required in real time transformation of school culture and practices in the 21st century digital and technologically satiated world. Considering science as a socio-cultural activity, AIS are significant in promoting teaching and learning of STEM for the common good! And as we have noted in the theoretical framework to this dissertation, in an activity system, tools are critical in transforming objects into outcomes mediated by community and sets of rules and norms. In pedagogical gerunds, effective teaching of STEM takes place when educators scaffold instructional and content objectives at relevant developmental levels of their students. Since 'our students are digital natives (as Nancy noted), it becomes imperative for STEM educators to operate at a conceptual phase and worldviews relevant and in alignment with their development to effect any conceptual change. It is therefore worth noting that Sphero educators and other teachers demonstrating skills are pedagogically operating at the very zone proximal of their student's digital developmental stages. In the STEM classrooms, teaching among others entails scaffolding what is expected of their students so they can challenge themselves in the mastery of scientific concepts and skills. Teachers do this by letting students operates the AIS during STEM lessons and fade their pedagogical instructions as soon as students become confident with the AIS.

Furthermore, in response to the research question on the top three skills of the 21st century STEM educators, respondents' views were divergent but convergent on some. One of the top skills listed is computational skill. Others indicated digital cultural skills, creativity, coding, programing, designing, digital flexibility just to enunciate a few. These skills were clustered during pre-coding and coding phases and a word cloud data was uploaded in Dedoose and generated the following word cloud image.

Figure 11

Word cloud data

Note: Word cloud data generated in Dedoose software suite.

Digital skills, creativity, technology, computational thinking, technological transformative skills were deemed most essential to being in a 21st century STEM educator according to the data and as illustrated above (Figure 11). Surprisingly, *pedagogical skill* was mentioned only once. By inference, there seems to be a shift in perceptions about the skills educators' exhibit or are anticipated to possess in contemporary STEM classrooms. As one of the respondents (Nancy) indicated, these skills are essential in the 21st century STEM educators in "the[ir] ability to relate to students through the lessons they are teaching." This is also important because these responses are from some STEM educators themselves considered and certified as experts. It will be insightful to have holistic data from students, administrators, teacher unions, policy makers and other stakeholders in STEM education. While such data is beyond the scope of the current dissertation, it is anticipated that future research will interrogate all these stakeholders in STEM. Since this is one of the primary data on this specific topic and AIS and the Sphero, I look forward to a longitudinal as well as a quantitative data in the very near future that explores these lingering questions on AIS and digital technologies in STEM classrooms.

4:3 Conclusion

Data is key to unlocking qualitative research (Charmaz, 2006; Creswell, 2018; Richardson & Pierre, 2015; Wolcott, 1994). In this chapter, I have briefly described the dissertation method with a highlight on the data analysis process. I have noted the kinds of data collected and I offered a critical analysis of the data through the process described in the previous chapter and as recapitulated briefly at the beginning of this chapter. It should be noted that five research subjects contributed to the primary data for this dissertation topic: *Exploring the use of Artificial Intelligent Systems in STEM classrooms.* The data were anonymized ostensibly in conformity with agreed IRB protocols to protect the integrity as well as to prevent traceability of the primary data sources and easily identifiable personal cues. The data were coalesced into one document and each of the responses to each question aggregated accordingly. As indicated in the method section, from this initial data organizational stage, the Macros function in Microsoft Word was enabled to transform the document for further analysis in the Dedoose software suite. After a meticulous analysis of the data, codes were assigned to emerging themes and concepts inter alia the research questions and the theoretical frameworks. Indeed, as Holton (2007) once indicated, “it is through coding that the conceptual abstraction of data and its reintegration as theory takes place” (p.265). In view of this, I have re-analyzed and re-coded the data-similar and convergent themes were merged with twelve themes which formed or constituted the core of the final data analysis of this chapter. The twelve themes were further synthesized into seven distinct themes due to their similarities in nature and type of theoretical frameworks, among others. It is worth noting that these processes of coding and data were cyclical until a point where no new theme/s emerged. The emergent themes constituted the foci of the data analysis and findings reported in this chapter.

In brief, artificial intelligent systems in STEM classrooms remains an emerging but crucial contemporary phenomenon for educators and learners as well as stakeholders in education especially at the K-12 level. Currently, there is a proliferation of AIS and digital technologies within and outside of the educational landscape. A review of the literature shows that some school districts are embracing and intentionally incorporating these into their respective STEM programs. It is worth noting that there exists divergent AIS and digital technologies. Despite these, there is sparsity of qualitative data and research on the significance and impact of AIS on STEM classrooms from the perspectives of teachers versatile and applying these. This dissertation focused exclusively on STEM educators, formally trained, certified to use Sphero educational robots and applications at the K-12 level in the USA. The data and the emergent themes and concepts adduced above echoes the significance of the use of AIS and digital technology at the K-12 STEM classrooms through the conceptual framework of activity theory or cultural historical activity theory (CHAT). Indeed, as one of the respondents noted, *"we are just beginning to implement learning about AI and right now we reflect the infancy of AI in the real world. Students will be using micro-controllers and other digital tech to design and create solutions to problems they see in the world. This mirrors what is going on in the real world".* The findings in this chapter is a litmus test for the applications of these new technologies in STEM classrooms and other educational activities. As research participants have indicated, *we are just at the beginning* of the incorporation of AIS and digital technologies as core constituents in pedagogical practices in the 21st century classrooms markedly suffused by digital culture. Indeed, an era of digital multiculturalism and in an extraordinary coincidence towards a renewed fervor in teaching STEM in an interdisciplinary manner. In the proceeding chapter, these emergent concepts and theories from the data will be discussed and expatiated in terms of their significance to STEM classrooms, among others in view of the theoretical framework of the dissertation study. I believe the qualitative data analyzed here will also serve as an important primary data for future research on the proliferation of artificial intelligent systems, digital culture, STEM education as well as inform theories of teaching and learning. As one of the research participants have noted, we are indeed *at the beginning* of the impact of artificial intelligent systems in STEM classrooms. Undoubtedly, this critical research has given cause to retrofit and retrain our professional educators towards the applications of artificial intelligent systems in their respective STEM classrooms.

Chapter 5: Discussion

5:0 Preliminary Comment

There is a renewed interest towards the integrative approach to teaching-learning STEM. As expatiated in the introductory and research data analysis Chapters, there have been many policies and programs formulated towards the introduction and implementation of robust STEM education in K-12 and collegiate curricula. As a matter of extraordinary coincidence, there is a proliferation of artificial intelligent systems coterminous with digital technological culture and worldviews (Archibugi, 2002; Bonk, 2012; Glenn, 1989; Graesser, 2006). Technology disrupts institutions and professional dynamics (Langer, 2019) and drives science and vice versa. This further bolsters the assertion that technology and science are inexplicably interconnected. AIS technologies seem to be driving scientific innovations and research with implications for STEM education and pedagogical practices especially in the 21^{st} century in a unique way. One of the transformative indicators is the changing trend in the "mortar, brick and slate" educational spaces and approach to teaching and learning of STEM. The traditional medley of dynamics between teachers, students and school administration and pedagogical practices and all the scope of education has been impacted in many places due to the applications of AIS and digital technologies such as smart boards, electronic based attendance tracking systems, availability of scientific data to students in real time. In addition, robotics, coding and STEM boot camps and clinics continue to saturate K-12 and collegiate programs and the communities across the USA. Industries and corporations such as AT & T (Kids Coding Camp, AT & T Women in STEM careers), Regeneron (Science Talent Search), Google STEM programs, Facebook-Sphero STEM projects, NYC (Summer STEM Camps) are sponsoring and advancing novel science educational activities. This new thrust *ipso facto* is disrupting every fabric of society and way of life such as education and social interactions, and school administrations (Langer, 2018). AIS has become a *sine qua non* in STEM educational systems and activities. As an act of extraordinary coincidence, the COVID-19 pandemic disrupted global educational systems as schools were closed unexpectedly. With the presence of modern technological platforms (Google classrooms and Jamboard, Zoom, Adobe Webinar, Microsoft Academy), schools, and academic works continued virtually despite some initial hiccups. The current dissertation research study and responses from participants on the use of AIS and digital technologies on STEM education seem to reify these changing trends. In the preceding chapter, the data from the survey were coded including memos, analyzed and several themes emerged. From these clusters of emerging themes, seven have been discussed here in terms of their relevance to STEM educational activities!

In the first part of this chapter, I have discussed the significance of artificial intelligent systems and digital technologies to STEM classrooms. The second part explored the significance of STEM education-the emerging and merging trends of AIS and the quest for the next generation of science standards and reforms. Thirdly, there is an aggregated empirical evidence about the significance of best methodologies such as the project/problem-based in teaching and learning science. This part of the chapter examined the project-based methods as an activity in the context of AIS in STEM classrooms in view of the theoretical framework of the dissertation study. The fourth part delved into the notion of creativity in the STEM classroom while the fifth part examined expansive learning with the impact of AIS. The sixth part adduces the case for computational thinking skills in STEM classrooms. Responses from the survey suggests AIS and digital technologies are significant in scaffolding STEM lessons. This was followed by an analysis of the epistemological significance of the Vygotskian zone of proximal development (ZPD) and how STEM educators can apply AIS to effectively promote academic rigors in an ever-changing epistemological ecology of digital multicultural classrooms. In this perspective, the dissertation dissected the notion of multicultural STEM classrooms in the wake of emerging AIS and digital cultures. Indeed, there is an emerging *digital multiculturalism* that embraces the abyss of epistemologies of every nook and cranny of the world especially in the content area of STEM education. It seems the world's diverse cultures are connected to the *digital multicultural grid*. Hence there is no more accepting the Eurocentric notion of multiculturalism. But to what extent does ZPD reflect the emergence of digital *multiculturalism*? These and other questions are also critically analyzed in view of their import to STEM classrooms. Finally, the study discussed the significance of the STEM classrooms during the recent pandemic and makes the case for optimizing pedagogical application of AIS and digital technologies in creating authentic teaching and learning spaces that promotes equity, access, and rigor in the 21st century world. In view of the above, I have critically examined the significance of AIS in STEM classrooms in the ensuing paragraphs of this chapter through the conceptual framework of activity theory!

5.1 Significance of Artificial Intelligent Systems to STEM Education

Firstly, the applications of AIS such as the Micro Bit, LEGO, Sphero bolts in classrooms is consistent with the STEM reform movement and objective in the United States. The disciplines and practice of science, technology, engineering, and mathematics (STEM) and allied intellectual pursuits drives human progress and development. There is a litany of erudite scholars in these fields such as Pythagoras, Aristotle, Newton, Einstein, Marie Curie, and Galileo just to mention a few. Their pioneering scientific works have laid a solid foundation and continue to shape the trajectory and progress of STEM practices and education in contemporary times. The fruits of these include the Great Pyramids of Egypt, discovery of medicines and other technologies by the Aztecs of Mexico, the Great Walls of China, the great roads of the Great Roman Empire just to enunciate a few. The industrial and post-industrial revolutions have also shaped the scientific world through the inventions of modern computers, powerful engines (auto, aeronautics, turbines), significant discovery about the solar system and deep space science, cancer, neuroscience, DNA and RNA, stem cell and bioengineering. These and others have created a significant repertoire of intellectual works, created wealth, and improved the quality of life of humans.

However, several events including empirical studies preceding the 1990s in the United States precipitated in the call for a reform in the studying of these disciplines and the emergence of the term STEM education. Some scholars of science education (Land, 2013; Sanders, 2009; Thomas & Williams, 2009) have suggested that the luster and competitiveness in science and technology dissipated in the USA in the 1950s. And as Cowen (2011) noted in his incisive piece, *The Great Stagnation,* the US experienced scientific as well as economic stagnations during these periods. In 1957, the USSR (now Russia), surreptitiously designed and launched the first satellite, Sputnik I into orbit. This event and others served as catalysts in the renewed effort to advance STEM education at the echelons of political and congressional leaderships in the United States- to make available resources and policy guidelines to ensure American students and the public have access to education and training to become competitive and leaders in STEM. Among others, it led to the creation of the *National Aeronautics and Space Administration* (NASA). This policy framework and support for the study of STEM accelerated and precipitated in the first American Astronauts landing on the moon (Sanders, 2009; Land, 2013). The United States once again carved a niche in the scientific and technological arena throughout the 1970-80s but began to recede. Many empirical studies and reports such as the National Commission on Excellence in Education: *A Nation at Risk: The Imperative for Educational Reform* (1983); the American Association for the Advancement of Science (AAAS): Project 2061 and several initiatives of the *National Science Foundation* (NSF) towards STEM education re-ignited a renewed symphony of calls for reform.

It is important to note that at this time, the acronym, SMET (Science, mathematics, engineering and Technology) also dissipated into the scientific literature of the reform movement in education in the US (Breiner et al., 2012; Ostler, 2012; Sanders, 2009). Nevertheless, many efforts at reforming educational systems especially STEM at the K-12 level in the United States were not fruitful due to an avalanche of factors such as, lack of coordination within numerous agencies, commissions, and stakeholders (Breiner et al., 2012; Land, 2013; Ostler, 2012; Sanders, 2009).

However, in the 1990s, the acronym STEM entered the lexicon of science education (Sanders, 2009, 2010; Yu et al, 2016). Scholars (Ostler, 2012; Sanders, 2009) believed that Charles Vela, a founder of the *Center for the Advancement of Hispanics in Science and Engineering Education* (CHASEE) used the acronym in the context of his STEM institute geared towards advancing the scientific skills of gifted students in Washington, the District of Columbia. Dr Vela served in myriads of scientific and social policy committees and it is theorized the term was eventually introduced at the *NSF* in the 1990s. It is believed STEM was derived from the earlier NFS acronym SMET-Science, Mathematics, Engineering and Technology (Frey, 2018). It is believed that an NSF official disparaged the term SMET as it seemed to connote derogatory sentiments. In response, Ramaley purportedly purged SMET and replaced it with the acronym STEM (Sanders, 2009). Citational evidence conducted by some scholars such as Chang et al. (2016) also affirms the emergence and frequency of the term STEM in scientific journals and research across the world around this time. Regardless of the two versions of the emergence of the acronym STEM, there is no doubt that because the two scholars namely, Vela and Ramaley were associated with the NFS, the acronym and the concepts it stands for reflects trends in reforming science education in the US. STEM became the crucible for the debate on the global competitiveness of science education and the notion that US students were lagging in those fields in comparison with others from industrialized countries. Ironically, there have been unprecedented demands for workers with STEM expertise and skills. Some scholars speculated that one of the reasons for the above situations was that STEM subjects were taught *in isolation* with each other perhaps with outmoded pedagogical approaches (Breiner et al., 2012; Land, 2013; Ostler, 2012; Sanders, 2009) and tools. As a result of these, many experts in the STEM fields purportedly were immigrants and these generated copious debates on national security and the role of American competitiveness in these fields in the global arena. To curtail these trends, scholars, policy, and industrial experts called for the recognition of the multidisciplinary and interdisciplinary nature of these subjects. As Frey (2018) poignantly noted,

> although many countries utilize the STEM acronym, there is little consensus about its meaning. When people refer to the multidisciplinary nature of STEM, they are generally focusing on the four different subject disciplines working independently. However, the interdisciplinary nature of STEM refers to the integration of knowledge and modes of thinking drawn from these four disciplines. (p.1620)

Thus "the introduction to STEM can be a variety of activities, but generally speaking, it usually includes the replacement of traditional lecture-based teaching strategies with more inquiry and project-based approaches" (Breiner et al., 2012, p.3). It should be emphasized that science, technology, engineering, and mathematics have outstanding history and rigor independent of each other in academia spanning several centuries and educational reforms. However, these subjects lacked the integrative, interdisciplinary, and cross-conceptual and practical approach. The movement in STEM among others is to emphasize these and partly in response to the global trends and demands in the field. After all, Hunter-Doniger and Sydow (2016) have noted "…students need the ability to understand and make connections between a variety of disciplines" (p.160).

Furthermore, the above progression towards STEM, aligned and partly coincided with the advent of digital culture concomitantly with the proliferation of AIS as discussed extensively in the *Literature Review, Method* and the *Data Analysis* Chapters of this dissertation. Indeed, the objective of STEM educational reform in the USA has become coterminous with a renewed call for a new approach in the education of the next generation of scientists versatile with skills relevant to their time and the world (albeit the 21st century) and the increasing demand by employers and corporations. This requires a paradigm shift in the manner teachers approach teaching STEM in a digital world satiated with AIS and technologies. And as Paulo Freire (1969) once noted, "human beings constantly create and re-create their knowledge, in that they are inconclusive, historical beings engaged in a permanent act of discovery" (p.119). The nature of AIS continues to chart new pathways driving human ingenuity characterized in the re-creation of scientific knowledge (albeit STEM) in our current educational systems. Thus, considering the "classroom" as an activity system (Engeström,1990, 2007, 2011, 2014; Engeström, Miettinen & Punamaki, 2007), AIS such as the Sphero, are of pedagogical significance for teaching and advancing STEM educational scholarships.

In brief, historical antecedents, globalization, the urge towards American competitiveness in STEM and lack thereof has generated copious debates and policy discourses about these disciplines. This attained its apogee in the 1990s with the introduction of the acronym, STEM to pitch for an interdisciplinary and integrative approach to teaching and learning of these subjects in response to the factors enunciated above. As Sanders (2009) correctly noted, at least four organization within the STEM community namely AAAS: 1989 *Science For all Americans*, 1993 *Benchmarks for Science Literacy;* Accreditation Board for Engineering and Technology (ABET):2000; National Council of Teachers of Mathematics (NCTM): 1989, 2000 and National

Research Council (NRC) 1996 recommended reforms, underscores the need towards an integrated approach to these disciplines in the United States. AIS and digital classrooms are poised to drive and attain the objectives of STEM reforms if educators are intentional in identifying and applying them pedagogically during STEM educational activities. The current qualitative data analysis from the study supports this. Indeed, respondents believe AIS promotes interdisciplinary teaching-learning of STEM.

5:2 Artificial Intelligent Systems, STEM, and the Next Generation of Science Standards

Secondly, AIS in the STEM classroom is also consistent and aligns with the introduction of the *Next Generation of Science Standards* (NGSS) principles and objectives. One of the central theses in support of the *integrative* approach to STEM education is that these subjects are intrinsically related in content, concepts, and pedagogical practices. Practitioners of these disciplines in real life often use principles, cross-concepts in resolving, inquiring into problems, or building or creating products, in collaboration with their peers and experts. For example, *NASA* missions typically involve many scientists including engine and propulsion engineers, electricians, mathematicians, radio and telecommunications experts, the mission crew, and many other scientists. Each brings their diverse disciplinary skills and knowledge to the design, preparation, mission, and post mission of the project. In essence, whereas these disciplines have often been taught as independent entities, in real life existential situations, they are practiced in integrative ways hence the quest for an interdisciplinary trajectory in STEM classrooms. After all, as Aristotle (purportedly said), *the whole is better than the sum of the individual*. This is because, students will learn and acquire core concepts and skills holistically with a potential for synergistic impact on STEM education. Evidence in this study has shown that AIS in STEM classrooms advances these cross-cutting and interdisciplinary approaches to teaching of science fervently advocated by the proponents of this approach. We saw overwhelming empirical evidence in the data analysis sections that the Sphero have been applied in interdisciplinary STEM classrooms by educators in the field of Mathematics, Robotics, Arts, Biology, and others.

Indeed, to test the above hypothesis further, the second dissertation question was framed thus: *Given that digital technology is transforming contemporary society in every facet. How/What does AIS tell us about how digital technology impacts STEM pedagogy?*

The Sphero bolts and applications offers many functions in integrative teaching of STEM. Teachers have and continue to use Sphero to teach STEM topics such as geometric figures, modeling and demonstrating biologic systems, in 3D(dimensional) models, cross-cutting principles just to mention a few. As anticipated, participant's responses appeared diverse but convergent on the significance of AIS especially the use of Sphero during STEM educational activities. For example, one participant indicates: "I think the technology of Sphero is important for students to learn…" and "True AI systems will become important in the future to ready students for future careers". Empirical evidence in the current dissertation study points to the increasing demand for the incorporation of AIS into STEM classrooms to prepare the current and ultimately future generation of students along the trajectory of careers. Currently, it is believed that nearly half a million students are using Sphero robots and educational applications in their respective STEM classrooms at the K-12 levels in the USA alone. There is an increase in the application of AIS in industry and workplaces such as healthcare analytics, diagnostics, and disease modelling in clinical and pharmaceutical research. In bioengineering, AIS and digital technologies are used to model and study cellular morphology and physiology in real time in 2D or 3D structures and bioprinting of biologic systems, among others. In a recent paper entitled**,** *Cosmological constraints with deep learning from KiDS-450 weak lensing maps* **(**Fluri et al., 2019*)* scientists have applied the principles of *facial recognition technologies* into an AIS system to probe the universe on the enigma of dark matter and dark energy. Dark matter and energy are generally elusive to telescopic lenses and other cosmological observational tools due to weak gravitational lensing. So, they programmed computers through neural networks tools to "…extract more information from the data than previous approaches. We believe that this usage of machine learning in cosmology will have many future applications" (September 25, 2019). These principles are embedded in the AIS and other technologies associated with the Sphero apps and others. Indeed, another research participant in the current study felt the Sphero app helps him "develop diverse STEM content and serves as a tool to effective teaching and learning many scientific concepts simultaneously unlike the textbook approach which limits STEM to one or few perspectives". Students are already familiar with most of these AIS outside of the domain of the classroom and recent research and empirical evidence (Irzik & Nola, 2009; Jackson & Graesser,2006; Madden et al., 2013; Palfrey & Gasser, 2013; Sottilare et al., 2013) seems to substantiate this assertion. As one of the research participants, Arinze have noted

> digital technology is clearly changing the way society acts and accesses many things. In education, it could be transformative if teachers learned to use it properly as a tool and a step up in educational practices and not just a replacement for non-digital work. This is not just in the context of Sphero but in the context of educational technology in general

This also gives credence to the notion that the application of digital technology transforms the STEM classroom as it does in the real world in which teachers assign students problems to be solved with AIS and tools (Combi, 2016; Buckingham & Willette, 2006; Fogarty et al., 2011; Graesser, 2016;Palfrey et al., 2013; Rowe et al., 2010). This approach, known in pedagogical scholarship as project-based-learning (PBL), has become increasingly correlated with the application of AIS in STEM educational activities including teaching and learning. It challenges educators to teach science in a way that learners apply scientific and cross-cutting principles to real life enigmas as practitioners in STEM classrooms or educational activities.

In brief, the outcome of the current dissertation study suggests that the NGSS remains an opportunity for educators to teach and advance STEM educational activities in a digital culture with appropriate and current pedagogical resources such as AIS and available digital technologies.

5:3 Applications of Artificial Intelligent Systems in Project-Based Teaching Methods

Thirdly, several teaching approaches or methodologies abound in STEM such as Peer Teaching, Inquiry-Based Learning Methods, Culturally Responsive Teaching Methods, Problem-Solving Methods, Project-Based Teaching Methods, and the Differentiated Teaching Methods (Harris & de Bruin, 2018; Provenzo Jr. & Buxton, 2010; Moore, 2018). The advent and impact of AIS such as Sphero bolts, Micro bits, and apps on STEM classrooms serves an alternative and in addition to the traditional approaches to teaching. It has also created a well-spring of pedagogical opportunities in K-12 education in STEM related subjects and teacher preparatory programs. Indeed, the nature of STEM requires a new approach that reflects the interdisciplinary perspective and the anticipated skills intended to impact learners and society. STEM education requires methodologies that promote critical thinking and problem-solving skills, innovative and creative skills that are rigorous and in alignment with the rapid changes in the employment landscape of the 21st century. These views are extant as major themes in this dissertation study as discussed in the preceding chapter. In its policy position towards the implementation of STEM education, the NSTA noted in pertinent part: *"contextualizing science learning through compelling issues not only showcases applications of science and engineering, but doing so can also transform the* *learning experience itself such that more impactful learning outcomes can be achieved*" (Zeidler, 2014). One of the proven teaching methods (Lajoie, 2005; Riley,2012; Rowe et al., 2010) aligned with STEM education in this perspective is "Project-Based Learning (PBL)" or Problem-based learning (PBL). After all, as the NSTA noted, "both science and engineering are human endeavors that involve similar basic procedures; however, science involves exploration of the *natural world* seeking explanations—based on evidence—for objects, organisms, and phenomena encountered, while engineering focuses on solutions to problems in the *human-made world*". One of the basic procedural approaches to exploring the natural world for evidence in STEM entails a hands-on participation to facilitate teaching and learning in an activity system. Some studies (Graesser et al., 2006; Popenici & Kerr, 2007) have shown that when teachers package teaching through demonstrations and projects, learning objectives are attained and students often acquire invaluable and long-lasting skills due to their participation in the project-based approach.

Some scholars Miller and Krajcik (2019) are of the view that "PBL can reshape science education by engaging all learners in meaningful and robust knowledge building experiences" Other scholars such as De Simone (2008) believe that,

> problem-based Learning (PBL) is aligned with the constructivist framework that views learning and teaching as the active and meaningful inquiry and building of knowledge by learners. PBL fosters both inquiry-and knowledge-based approaches to problem solving. As an inquiry-based approach, its focus is on helping professionals such as teachers work through authentic, complex problems or case. (p.179)

One of the strengths of the PBL methods is that it is consistent with the constructivist approach to education in which the learner or learners are active participants in the construction of the corpus of knowledge. This is important in a *cultural-historical activity system* approach to STEM education. PBL is a form of human activity that requires the participation of all in the generation and transformation of the STEM classroom. Data from the current dissertation study has demonstrated that AIS and digital technologies serve pivotal roles in anchoring teaching STEM by structuring lesson plans for learners to participate in activities individually and collectively in the classroom that are meaningful and relatable to their worldviews and experiences.

In an attempt to advance the scholarship on the PBL process, some scholars (Pretz et al., 2003) have formulated a detailed seven-stage cycle thus: (1) the recognition or identification of a problem, (2) the definition and mental representation of the problem, (3) the development of a strategy to solve the problem, (4) the organization of knowledge concerning the problem, (5) the allocation of mental and physical resources to solving the problem, (6) the monitoring of progress toward the goal, and (7) the evaluation of the solution for accuracy. During the application of the Sphero to STEM *activity system* classrooms, educators identify and present specific problems or challenges to students as group projects or as individuals. This is often captioned in the lesson plan with very clear and defined objectives and directives for students. This may be construed as the first stage of the seven-stage PBL approach.

In the second stages, educators facilitate the definition of the problem to be solved by students. For instance, with AIS, students will brainstorm and develop some conceptual frameworks and speculate about the problem. This serves as a critical point of speculative discourse for students to talk to each other, develop social skills, analyze, and even begin developing their hypothesis about the problem. The third stage is synonymous to the apogee of the PBL. This is because at this point, the role of the teacher *fades* thus creating a crucial moment and opportunities for learners to strategize (either as individuals or groups) on solving the pending research question or conundrum associated with the project on their own accord. After all, in the STEM classroom, the teacher's role as facilitator is to simply scaffold students to use the AIS tool towards discovery including finding concrete solutions and offering scientific evidence and data. It also entails generating novel ideas or creating new frontiers of knowledge and scientific skills. Or simply put, construct their own ideas and theories based on data and evidence extrapolated from the PBL STEM classroom.

In the final phases of the seven-stage cycle, educators challenge students to generate and document data including their findings as reports, analyze these data and represent them as well as offering recommendations for future study, among others. The Sphero has several features such as graph function, documentation, and data-reporting in advancing STEM in the classroom and other educational activities. In addition, PBL presents real life scenarios or problems to students. It allows students to identify and clarify the problem, strategize, inquire, and speculate about the problem as well as the onerous opportunity to test their own hypothesis (Bereiter & Scardamalia 2006; Hmelo-Silver, 2004) This is consistent with the nature and practices of science (Kuhn, 2012; Sanders, 2009). By creating authentic educational spaces for students to work in groups, they develop vital group dynamics, problem-solving and critical thinking skills required in practitioners in STEM related activity systems. As one participant in this study notes,

> I use the Sphero as an introduction to coding and to robotics. Students start by driving for a few minutes and progress from there into coding with blocks. Students are then challenged to code the robots to do what they want them to do, or to solve the challenge. We can build this into Java or Python coding and add student built robots or devices and introduce AI.

Three distinct phases emerge from the application of AIS in STEM classrooms and aligns with PBL teaching. These are introductory, progress (intermediate), challenges (advance) teaching and learning in AIS STEM classrooms.

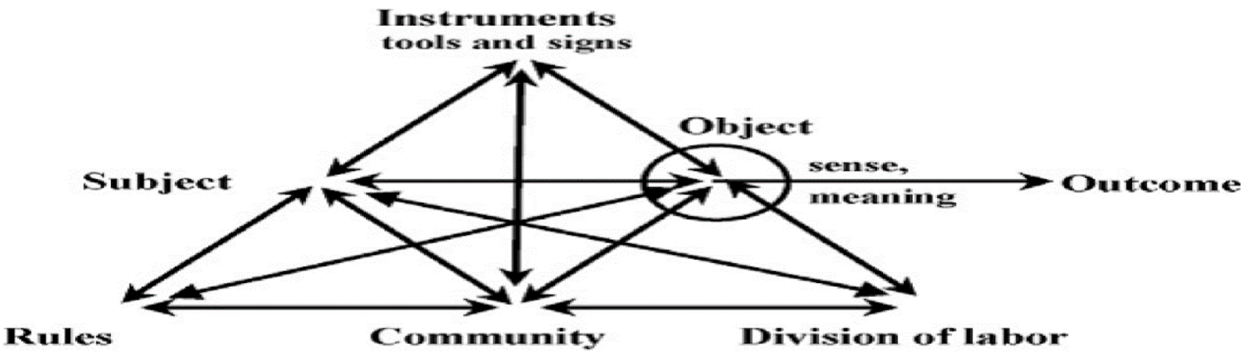
In the PBL AIS STEM classrooms, teachers lead learners to begin with the specific problem associated with their project. They ***'start'*** learning by driving the Sphero bolts out of sheer curiosity. This is an important pedagogical phase as it helps students gain a modicum of confidence and familiarize themselves about the matrix of the AIS system. The introductory activity through PBL gives them the basic first-hand experience, motivation and serves as a significant learning tool in their respective STEM classrooms. Such initial interactions with tools or artifacts are significant especially in the context of an activity theory system. It is key in teaching and learning in science education to gain the attention and the curiosity of learners and affirms one of the principles of activity theory. It captures the critical senses of the learner-sight, touch, hearing deemed components in perception theories in pedagogy. From this initial activity of driving the bolts, they then **"progress** from there into coding with blocks" albeit a high order approach to PBL in the STEM classroom. It is worth noting that 'blocks' features of the Sphero bolts are functionally versatile and gives teachers and learning endless opportunities to intentionally transfer their project designs into codes and programming languages with the bolts and apps. From these meaningful STEM activities, students may edit or recode and add other features as needed or as challenged. The transfer of these codes into Java or Python scripts signifies a *progression* from just an interaction into advanced learning using the Sphero AIS technologies. It is also an indication that learners have undergone a conceptual change of educational significance. Indeed, students can also gain in-depth knowledge and cross-conceptual skills and apply these to solve problems as well in real life by designing their own codes and building their own robots or devices. Indeed, as Emdin,

2010) noted "implementing these new approaches in science education can most directly be achieved through a culturally rich science curriculum or through methods by which an existing curriculum is made malleable enough to meet the students' needs" (p.3). Furthermore, PBL with AIS in STEM classrooms creates spaces for students to work on individually assigned projects and activities thus creating pedagogical opportunities for the co-production and conceptual change.

In addition, students work in groups to identify, design, strategize specific problems during their STEM lessons. For example, in building a maze with the Sphero robot and apps, students in a group are assigned specific roles such as writing and calibrating codes for distance, angles of contours, movement and stop codes, collection of data into graph codes and transferring these into advance Java scripts. In some situations, teachers can guide students to extrapolate linear or advanced mathematical equations of the movements of the Sphero bolt in real-time. These elaborate approach to a maze is consistent with the nature and the currents paradigm shifts towards making science reflective of real-life situations of STEM practitioners. In the context of the research theoretical framework of *activity theory*, it implies that students adhere to the community *rules and norms* and use available *tools and signs* (including language) to create a scientific solution or in the gerund of the theoretical framework of this study, "an outcome". These elements constitute the core components of an activity system. This is illustrated by an activity triangle (Engeström, 2007) below worth discussing.

Figure 12

The third-generation model of activity theory



Note: This figure (12) adapted from Engeström (2017) details the various components of activity theory.

In an activity system (Engeström,2017; Lee & Roth,2007), PBL with AIS STEM classroom, the instrument such as the Sphero bolt or any AIS technologies are important. The Sphero serves as a cultural tool and sign in teaching STEM education. In *an activity system*, the Sphero and applications are not an end in themselves for educators. Rather, they are important experiential tools in the STEM classroom so the teacher can design his lessons for students during PBL sessions to master a scientific concept, theory, product, or principle through intentional and meaningful human activity. The AIS STEM classroom constitutes what is known in an *activity system* as a *community (*Engeström, 1987, 1993, 1996, 2001; Fire & Casstevens, 2013; Foot, 2001; Holland & Reeves, 1996; Kaptelinin & Nardi, 2006; Miettinen & Engeström, 1999). The community entails the teacher, learners, scientific and professional groups, individual and collective assigned groups on specific projects using the Sphero bolt. The teacher can reorganize this learning community in accordance with the topic and nature of concepts, natural phenomena, and principle being studied in the STEM classroom. This can be the size of the group; subgroup; characteristics, features and disposition and aptitude of the students, number of Sphero bolts available, time allotted for STEM classes and other parameters. These factors are critical in the lesson planning process for STEM classrooms. STEM teachers and collaborators determine the size and constituents of each group. As a microcosm of the larger community, activity theory-based classrooms also have rules, norms, policies, directives that are explicitly codified or known to the STEM classroom.

Additionally, they may write their own *rules* and *norms* and adhere to these during the application of AIS and in STEM classrooms. For instance, while the STEM teacher gives specific protocol for students to follow, the students in turn may rewrite these rules such as assigning each member of the group tasks and works to do to accomplish teaching and learning objectives. For example, the Sphero has a “refactor” function. Using the *refactor function*, students can rewrite a specific code instruction or could re-write or recode the initial function in Java Script. While the code changes, the external intended behavior of the initial code may remain the same after the *refactoring* procedures. This process creates another activity system (Engeström, 2017, 2018; Leont’ev, 1978; Vygotsky 1978) feature that is *division of labor* within the AIS STEM classroom-coders, record keepers, cleaners, table organizers, among others.

The concept of the division of labor as we discussed earlier transcends human social systems and gives credence to the diversity and uniqueness of each member of society. No one indeed is an island as the aphorism goes and no individual can accomplish the goals of society alone. This is beautifully captured in an African proverb-*sticks in a bundle are unbreakable!* As a result, there is consistent empirical evidence about the diverse roles each members of society (groups, individuals, professional bodies, institutions) engage in towards the attainment and achievement of goals and objectives of teaching and learning of STEM. Division of labor also transcends democratic, socialists or monarchical societies into contemporary times. In our current educational sector, the concept is even significant in the promotion and learning of STEM. Indeed, *division of labor refers to horizontal division of tasks and vertical division of power and status* (Engeström, 1987). This is an important component in an activity system reflective of CHAT. Activity theorists recognize the central roles of labor in society or “system” of human society. For example, in the STEM classroom, teaching may be construed as a form of labor and obviously, learning also constitutes an important bloc of labor. However, each person performs his or her labor differently following specific, agreeable, or operational rules to accomplish and attain desired goals and outcomes. In performing these roles, proponents of CHAT believe that every participant has his or her own roles in anticipation of the group’s objectives. Hence there is a tacit recognition of the division of labor within the *activity system*. Each participant in an activity system overtly or covertly holds a cue or views of an impending project in focus in a STEM classroom. In the STEM classroom, the teacher’s roles, as we have noted, are decisive in scaffolding the lesson through the provision of “tools” (AIS and digital technologies) so that learners could also participate in the labor. Division of labor entails a medley of verticality of power and in the case of the STEM classroom, the teacher has the vested authority and the recognition to plan, design and prepare for the lesson. During the *actual* STEM activity session in the classroom however, the teacher’s role fades away or changes in dynamics. Consequently, there is a shift in power and status as the teacher assigns the STEM activity to his students with AIS technologies such as the Sphero! After the introduction, learners assume greater and of the teaching and learning procedures through active and conscious participation using the AIS.

Furthermore, activity is a goal driven enterprise. For instance, the farmer engages in planting (as an activity) in anticipation of transforming seeds into fruits, grains, or some product or outcome. Everything in nature as Aristotle once said has a goal or as in Greek, “a telos”.

Everything including human action has teleological focus. Proponent of activity theory postulates that human action leads to an *outcome* (Engeström et al., 2007; Hasan et al., 2014; Kaptelinin & Nardi, 2017). In pedagogical parlance, teaching and learning should be transformative and evidentiary to generate an *outcome*.

In brief, ‘object’ is the outcome or expectations that an instrument in the hands of a subject in an activity system herein a STEM classroom or space is attained. Simply put, teaching objective translates into learning objectives for students as they apply artificial intelligent systems such as the Sphero bolts apps in the STEM classroom. Such an approach obviously is a departure from the often rigid hitherto lecture, didactic, textbook, bookish approach to teaching STEM which is increasingly perceived to be antiquated and inadequate especially among digital multicultural learners. In a Sphero oriented STEM classroom, there is the immediacy of activity “outcome” in the project report including their descriptions, hypotheses, data collection and analyses. In brief, the application of AIS such as Sphero in STEM classrooms create a unique *activity system-based* approach to teaching science where learners are able to work collaboratively on projects akin to real life situations in which they use the PBL strategy to accomplish learning objectives with the use of artificial intelligent systems. To some extent, it lends credence to creativity and serves as a pedestal for expansive learning in the context of cultural-historical activity theory which will be discussed below.

5:4 Artificial Intelligent Systems and Creativity in STEM education

Fourthly, one of the objectives of teaching (STEM) is to tap into the creative gulf of the learner. This trait is critical to a conceptual change (Vosniadou, 2013) and the development and advancement of core scientific skills. And as Piaget (1953) once said, *the principal goal of education is to create men who are capable of doing new things, not simply of repeating what* *other generations have done – men who are creative, inventive and discoverers*. Human beings by nature are creative entities that perpetually strive to explore their environment, attempt to understand nature, and use tools to shape nature, among others. And as the popular aphorism suggests, the stone age did not end because there was a shortage of stones! Rather, human creativity with tools transformed their environments into new bustling technological feats and inventions. And as in the words of Einstein, *creativity is contagious* hence the need to 'pass it on" perhaps through educational activity systems such as STEM classrooms.

Definitionally, Harris and De Bruin (2018) offer an apt description in the *Oxford Research Encyclopedia of Education* on creativity thus: "creativity discourses commonly attend to creative ability, influence, and assessment along three broad themes: the physical environment, pedagogical practices and learner traits, and the role of partnerships in and beyond the school". These three broad themes in the opinion of the scholars, Harris and De Bruin (2018, *Creativity in Education*) are of pedagogical significance in STEM classrooms. In a recent research study, Harris and De Bruin (2018) postulated the thesis that,

> Effective and informed pedagogical applications by teachers in the classroom can generate positive influence and outcomes to promoting creative climates. Creative relationships between teachers and learners are dependent on the nurturing and promotive aspects of interactions and activities that can potentially fracture the siloed nature of subjects and predominant teaching practices. Learning and teaching that reinforces effective pedagogic environments can promote high expectations, mutual respect, modelling of creative attitudes, flexibility and enhanced dialogue interactions, and indeed creativity. (p.172)

STEM classrooms have spaces-a physical environment in which educators carefully engage learners in the study of science. STEM as a form of human activity occurs within human spaces albeit teaching and learning environments (classrooms). Teaching and learning environments are not singular and cloistered system/s. Rather, there is a pluralism reflective of multiple cultures as scientific knowledge remains diverse. Of course, STEM by its very nature is interdisciplinary and multidisciplinary hence in activity systems it is important to scaffold and approach teaching from multicultural perspectives and lenses using the classroom as a microcosm of the larger society. Both the literature reviewed, and the actual dissertation study data suggests that technology is essential in promoting diverse teaching environments in advancing creativity in STEM education. This includes AIS, digital technologies, laboratories and libraries, and others. In historical *activity systems* AIS is both a "physical" and "mental" *tool* in the STEM classroom. As a physical tool, AIS such as the Sphero, Micro Bit or LEGO bots are tangible and available to both educators and students during teaching and learning of STEM. The Sphero Bolts is described as "an app-enabled robotic ball that provides endless opportunities to be creative and have fun while learning. Program with the Sphero Edu app from nearly any mobile or desktop device, discover awesome community-created activities, or just drive and play. BOLT was built to shine with a brilliant 8x8 LED Matrix that animates and displays real-time data. Create and customize games and learn to code by drawing on your screen, using Scratch™ blocks, or writing JavaScript text programs" (www.stemfinity.com/Sphero-Bolt-Kit.2020). It has an inbuilt compass, waterproof ball, ambient light sensors, equipped with Bluetooth and infrared communication, remote charging pod and a gyrating gearing system. In addition to these physical features, the bolt also has nonphysical features. Thus, the Sphero bolt app in CHAT semantics serves as a "mental tool". As a mental tool, the Sphero has digital artifacts and in-built language including coding and programming language

(JavaScript, Scratching Blocks) and applications that are compatible with digital platforms such as iOS and Android operating systems. Users can download the app on any modern computational devices and smartboard and synchronize entire STEM projects or lessons with the Sphero bolts. Educators can collect real time data on students' projects such as progress of work in class or remotely, assessment data and trends of students' progress, as a diagnostic tool to determine students' learning progressions, among others. These physical features are versatile and enable users (STEM educators) to design meaningful and relevant science educational activities around the bolt in teaching. Thus, an educator can create a teaching-learning "community" using both the physical and non-physical features of the AIS digit al technological tool in teaching STEM. In brief, AIS promotes creativity in the teaching and learning of STEM.

In AT/CHAT, the Sphero bolt and app mediates and transforms teaching of STEM. Such transformation is evident at STEM activities in the classroom and on the platforms associated with the tool. In the words of Engeström (1993) tools and objects, "refers to the 'raw material' or 'problem space' at which the activity is directed, and which is molded or transformed into outcomes with the help of physical and symbolic, external and internal *tools*" (p.67). Such outcomes include evidence of students' progress measured in assessments, conceptual changes, project works, presentations. By making meaningful use of these essential physical environments, especially technology, educators can and do create relevant *socio-cultural pedagogical ecologies* for effective and creative STEM classroom activities to generate and advance creative traits in learners. This is possible if they employ "pedagogical practices and learner traits" including the use of AIS in teaching STEM to expand their conceptual framework, skills, and learning objectives. Evidence in the current dissertation study as discussed in the preceding chapter suggests that AIS such as the Sphero promotes creativity through activity systems exemplified in

STEM classrooms. This piece argues for the scrutiny and identification of useful AIS and digital technologies to serve as tools, artifacts and platforms in the teaching and advancement of STEM classroom activities. While these AIS are not ends in themselves per se, there is probable cause currently to believe they promote creativity geared towards academic rigors especially in progressively diversified and digital multicultural STEM classrooms.

In a recent Gallup Poll (2019), "eighty-seven percent of teachers and 77% of parents agree that teaching approaches that inspire creativity in the learning process have a bigger payoff for students. Yet, students spend most of their time on traditional lessons that do little to encourage creativity, even though the growing availability of technology promises new ways of learning" (p.3). Technology here is broadly construed and includes digital technologies and AIS currently available to STEM educators and learners. There is thus an overwhelming opinion about the role of technology in generating creativity in education and in the context of this research, STEM classrooms where the Sphero and apps are being used to leverage pedagogical practices or activities. This seems to be a departure from the traditional teaching methods and lessons deemed antithetical to creativity. After all, as the Gallup Polls report sums it up: "creativity in learning produces positive critical outcomes for students, which are further enhanced when teachers leverage the full potential of technology" (p.3). While there is no definitive evidence that technology automatically enhances creativity, the current polls and research suggests that the presence and use of technology culminates in positive outcomes for student's creative repertoire. These positive *outcomes* are important as every STEM educator wishes to attain their teaching objectives in their classrooms. Such outcomes remain the goal of activity theory principles.

In an activity system, *tools, and artifacts* such as AIS technologies are mediatory to subjects and objects resulting in an "outcome" (Callaway, 2016; Engeström, 2007; Hasan &

Kazlauskas, 2014; Kuutti, 1996, 2005) in STEM classrooms. Teachers scaffold this process by introducing and leveraging teaching and learning of STEM with AIS and technologies so that learners through their interactions with these artifacts and tools in their environments create their diverse corpus of scientific knowledge (outcomes). By following specific *rules* (Kuutti, 1996) and interacting with each other in the STEM classrooms, they create an abyss of multiple learning experiences as they bring their diverse worldviews and experiences to study specific STEM topics or concepts in advancing scientific knowledge and discovery within specific contexts. And as indicated in the expose on activity theoretical concept, artifacts, and tools in the form of technology are meaningless unless it is framed in the contexts of pedagogical ecologies and learning contexts of time and space. Contexts in the use of AIS and digital technologies confers or imposes meaning to these technologies such as the Sphero in STEM classrooms "in which a transition from one stage to another is accomplished not as an evolving process but as a revolutionary process" (Vygotsky,1998, p.193) of desirable or sometimes serendipitous outcomes in science. While the current dissertation examined this matter through a qualitative approach, it is worth noting that the quantitative data in the Gallup Polls, nevertheless, appears to corroborate some of the key findings of my study about the roles of AIS and digital technologies in STEM classrooms in a multicultural digital world. Simply put, AIS such as the Sphero nurtures creativity in STEM classrooms.

5:5 Artificial Intelligent Systems and Expansive Learning

Fifthly, the notion and concept of creativity/expansive learning (Engeström, 2011, 2014; Plakitsi,2013) are contemporaneous with current cultural-historical activity theory (CHAT). In STEM classrooms, teachers' roles are pivotal towards the attainment of teaching-learning of STEM objectives culminating in this epistemological change. Conceptual change can be either qualitative or quantitative (Rand et al.,1996) or an admixture of these. It is anticipated that teaching

STEM with available tools, community, division of labor in an activity system, subjects should translate these into desired "outcome" (Vygotski,1978; Engeström,1988)). This outcome should lead to some epistemological transformation and the emergence of new perspectives; discarding misconceptions; confirmation of STEM beliefs; creativity; acquisition of new skills or the emergence of new teaching and learning objectives, among others.

Hence, a good STEM lesson leads to a modicum of epistemological change or in the lexicon of cultural-historical activity theory, an expansive learning through meaningful STEM activity with AIS technologies. Expansive learning has become increasingly significant in our understanding of activity theory. Proponents of this theory such as Engeström and Sannino (2010) believe expansive learning occurs "when learners learn something that is not yet there. In other words, the learners construct a new object and concept for their collective activity and implement this new object and concept" (p.2). Indeed, as Engeström, (1988) have observed:

> the essence of [expansive] learning activity is the production of objectively, societally new activity structures (including new objects, instruments, etc.) out of actions manifesting the inner contradictions of the preceding form of the activity in question. [Expansive] learning activity is mastery of expansion from actions to a new activity. While traditional schooling is essentially a subject-producing activity and traditional science is essentially an instrument-producing activity, [expansive] learning activity is an activity-producing activity. (p.125)

Simply put, teaching leads to an expansion of knowledge through meaningful human activity mediated by tools and artifacts. In the context of the research topic, the application of AIS and digital technologies in the STEM classroom creates expansive teaching and learning portfolios. It is also worth indicating that the nature of AIS and digital technology are *combinatorial*

(Brynjolfsson & McAfee, 2014; Yoo et al., 2010; Zittrain, 2006, 2008). By combining two sub-technologies, AIS can launch and create new content or corpus of scientific knowledge hitherto unknown. That is AIS can expand teaching and learning-transforming STEM classrooms through expanding concepts, contents, skills that truly embellish a 21st century digital classroom. For example, using Sphero bolts and apps, teachers can create STEM activities with codes and assign learners to *generate*, *design*, *create*, new codes and language in advance Java Scripts. In addition, teachers and students can extrapolate linear equations or other STEM related codes associated with the movement of the Sphero bolts during STEM activities in the classroom. These undoubtedly will bolster computational thinking skills. The ability of educators in a STEM classroom to scaffold students learning objectives in transforming these activities into new and emerging products and designs are consistent with expansive teaching and learning within the paradigm of the activity conceptual framework. This *ipso facto* exemplifies expansive teaching in a STEM activity system herein in the classroom as a *mastery of expansion from actions to a new activity* (Engeström, 1987). Furthermore, Engeström (1987) describes expansive learning activity within activity theory thus:

> The increasingly societal nature of work processes, their internal complexity and interconnectedness as well as their massive volumes in capital and capacity, are making it evident that, at least in periods of acute disturbance or intensive change, no one actually quite masters the work activity as a whole, though the control and planning of the whole is formally in the hands of the management. This creates something that may be called 'grey zones', areas of vacuum or 'no man's land', where initiative and determined action from practically any level of the corporate hierarchy may have unexpected effects.(pp.113–114)

This is seemingly consistent with the Vygotsky theory of learning-a key theoretical basis for the emergence of activity theory which has been at the epicenter of this dissertation study. There is evidence of STEM teachers and even learners designing and writing applications using AIS and digital platforms that are completely new in content and significant in teaching and learning. Educators are exploring these grey zones or in Vygotskian terms, "zone of proximal development"! These zones of proximal development are being transformed into "zones of precisions development" as AIS by nature encapsulates very definitive operational structures and content. The survey instrument for example probed into this and the response and analysis in the preceding chapter are significant to STEM. AIS in STEM classrooms creates a labyrinth of opportunity for STEM educators to generate and ingratiate in creativity with significance for expansive learning. Division of labor in STEM activity systems as discussed earlier, creates diverse teaching and learning opportunities in the classroom. Educators create meaningful and diverse activities for each student especially in a PBL approach. Each member under the tutelage of the educator actively contributes to the corpus of the STEM activity experience. The STEM classroom becomes a confluent point that synchronizes diverse scientific ideas, skills, and experiences. Students could be part of the teaching and learning process by being responsible participants in engaging each other, challenging pervading ideas, and developing hypotheses. They can also design, criticize, and accept criticisms from each other. It also helps nurture mutual understanding and challenges learners to formulate means to work out differences towards the completion of projects assigned to them in an AIS activity system STEM classroom. Such an approach changes the roles of a teacher as a facilitator and dismantles the walls of hitherto rigid teaching methodologies in science not compatible with contemporary digital age and interdisciplinary notion of STEM education.

5:6 AIS and Computational thinking Skills in STEM classrooms

Sixthly, education is a core constituent to social cohesion, development, productivity, and advancements. No educational system remains static per se as cultural, geographical, economic factors among others drives the changing trends and skills needed. At the beginning of the 20th century, basic literacy and proficiency in reading, writing and arithmetic were sufficient skills sets taught in schools to meet demands of potential employers and society. During those times, there existed an educated workforce for the increasing emergent and booming industrial economies (Bonks, 2018). However, these changed as the demands for different pods of the economy and technologies changed and shaped human productivity paving the way for diverse skills needed. Currently, there is an increasing discourse about teaching *computational thinking skills* (CTS) in our STEM curricula reflective of current digital worldviews satiated by AIS and digital technologies. CTS are currently in demand as the emergence and development of AIS continue to shape every facet of our world especially STEM fields.

According to Wing (2006), computational thinking skills entails "solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science" (p.33). This definition is very broad, and I believe it requires further analysis as it is relevant and significant to the dissertation study. Wing's expositions begin with solving problems as well as designing systems as core to CTS. As noted in the preceding paragraph, current educational reforms especially in STEM imposes an imperative on teachers to design their curricula such that they teach problem solving skills, so they become important pedagogical tools for students. This is done by assigning specific problems so that they can use available resources in their respective classrooms for scientific inquiry. CTS requires STEM educators to design systems for instance robotic codes or resources such as the Sphero bolts based on their science lessons. Thus, creating teaching opportunities for learners to create, rethink, reformulate and even recalibrate their own hypotheses. CTS also entails a careful *understanding of human behavior* which is also a core component to teaching and learning in the context of an activity system. For instance, some of the research participants indicated that during their AIS STEM lessons, they "let" (permit) their students to have some time to get used to the Sphero bolts-so that they can have ample time to explore the features and functions of the AIS, the apps and how the AIS communicates with computers/tablets associated with the bolts. Such initial encounters and discovery of the bolts is based on the fundamental premise that teaching begins from what is known to the unknown. This approach and understanding of human behavior are key to teaching computational thinking skills as well as teaching foundational skills on how computers AIS and digital technologies work as applicable to STEM education. CTS is also significant for STEM teachers as it encapsulates *pedagogical content knowledge* (PCK) that is, "…an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (Shulman, 1986, p.9). In the context of this doctoral dissertation PCK is an essential trait for STEM teachers to exhibit in a digital world. Schulman (1986) further argues that PCK,

> embodies the aspects of content most germane to its teachability. Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others . . . [It] also includes an understanding of

> what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning. (Shulman, 1986, p.9)

These definitions and expositions among others appear to project the teacher to a pedestal as an expert of PCK to the extent that students' perspectives and contribution of learning seems contingent on the teacher. Some scholars (Cochran et al., 1991) were concerned and accordingly reified Shulman's descriptions. For Cochran et al. (1991) PCK implies that,

> teachers differ from biologists, historians, writers, or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, experienced science teachers' knowledge of science is structured from a teaching perspective and is used as a basis for the construction of new knowledge in the field. (p.5)

This later exposition dichotomized teachers from actual practitioners of the content matter as well as the roles of students in the teaching and learning process. PCK is seemingly based on their expertise and more so on experience. And these experiences are critical in the construction of new PCK and skills during teaching. And as Darling- Hammond (1997) foresightedly noted: "To meet the needs of the 21st century, America's teachers are being asked to teach students with vastly different experiences, language backgrounds, cultures, talents, and needs to master more challenging content, and to do so for more effectively than they have ever done before" (p.2). And in this context, digital natives whose worldviews and experiences are marked by digital culture and to whom computational thinking skills remain significant. To understand this, during the dissertation study I intentionally chose STEM educators who have been trained and certified to use the Sphero. I believe that they have the best experience and expertise in PCK to use AIS in

STEM classrooms. I postulate that the application of AIS in STEM classrooms signifies teacher's advancement of PCK herein computational thinking skills. As one of the respondents noted, the Sphero "helped reinforce my limited coding skills and build those up a little. It provided a platform for scaffolded instruction and helped engage students". The research findings show that teachers use AIS herein the Sphero to generate STEM content and carefully use appropriate pedagogical practices in presenting scientific ideas in comprehensible ways to students' cognizance of their prior knowledge and skills. Thus, students can gain or acquire computational thinking skills from STEM educators through their participation in the AIS classrooms. As one of the key indicators of an educator, *pedagogical content knowledge,* implies STEM educator's proficiency in these skills. After all, as the aphorism goes *nemo dat quod non habet* (you cannot give what you do not have). It is hopeful that many STEM educators will embrace AIS such as the Sphero as core components of their PCK and classrooms to impact the *computational thinking skills* to the current digital natives and potentially future pods of students.

Furthermore, our contemporary educational structures have some relics of past educational systems. It includes place (school architecture), type and skills of the teachers, methodology used, administration and others. These determine the kinds of skills needed. For example, Plato's "academy" is among some of the earliest known structured educational systems or schools. The academy was a location where pupils gathered, and Plato and his successors taught them in accordance with the dominant methodology of the time-dialectics and the lecture methods. The immediate successor to Plato's academy was the famous "peripatetic" school of Aristotle where teachers and students walk around (peripatetic) during lectures. Students were trained or educated in the natural sciences as well as the arts, rhetoric, and persuasion. Thus, students during this era were anticipated to exhibit these skills. Roman educational system is worth mentioning here. There seems to be some unanimity about the influence of Greece on Roman educational system. While Horace noted in one of his works, *Epistles 2,1,156-7*: *Graecia capt a ferum victorem cepit et artis intulit agresti Latio* ("Greece, conquered, took captive her savage conqueror and brought the arts into rustic Latium), Cicero even made a more profound assertion in these words, "we, the Romans, have gone to school in Greece; we read their poets and learn them by heart, and then we think ourselves scholars and men of culture" (para.3). Cicero envisaged a distinctive educational system other than the previous. Indeed, for the Romans at the time, some of the hallmark of education is demonstrated by basic skills in literacy and numeracy and for those advancing into public service and leadership, rhetoric. By the Middle Ages, learning or educational systems declined in most parts of the western world. Even though learning in other parts of the world continued with the replacement of the Latin numerals with the Arabic numerals (which we still have today), there is a general consensus that teaching and learning markedly declined until the period of the Renaissance. The industrial revolution and colonialism also precipitated a new pod of educational system doused with pre-Middle Ages characteristics with the inclusion of both the liberal arts and vocational education. Teachers assiduously prepared students with vocational skills in high demands by industries as well as an ever-emerging middle level employers who needed clerical skills and other professions such as lawyers, clergy, and physicians. The proliferation of the railways and telecommunication created an efficient transportation system that linked many cities and countries in the world. This created the opportunity for the emergence of a correspondence educational system. Educators created course modules and mailed them to prospective students at varying locations. Indeed, this opens an opportunity for the working as well as the upper classes to both “access” education at their convenience. In addition, the 20th century created some form of axiomatic shifts in education. Due to both world wars, educational systems in many countries shifted to manufacturing of war machines, equipment, and computational technologies. Apprenticeship also emerged to train some of the manpower needed to use equipment and machines during this period. The advancement of artificial intelligence, and digital technologies and global competitiveness in science and engineering among others have created paradigm shifts in the kinds of skills and competence required in the world as reflected in the contemporary educational system.

However, there is evidence (Engeström, 2007, 2008, 2017) that sometimes, some educational policies and practices may or do become antiquated and irrelevant to prevailing worldviews or in the parlance of activity theory, “community”. This situation occurs when educational practices rigidly resist to be updated or become maligned with prevailing scientific community practices (Holbert, 2002). Scientific community is a broad concept that includes the environment such as the calendric data (year, era, epoch); culture, geophysical loci, linguistics, prevailing scientific practices, broader social expectations of the skills needed to practice and deemed as scientists. There is an aggregated evidence (Holbert, 2002) about the seismic shift and diverse skills of scientists at the beginning of the 21st century compared to prior centuries (beyond the scope of this dissertation study). As noted earlier, demands and productivity requires that educational institutions adapt and reflect these changing trends in the churning of each generation of human capital through appropriate applications and use of tools available. Considering the scope of science in this dissertation study as an “activity”, it implies examining the extent to which educational systems make use of prevailing tools in cultivating and shaping the skills of the current generation of scientists. In this perspective, STEM practices ought to be current and reflect prevailing generational skills. In the activity theory diagram above (Figures 2 & 3), there is a direct positional relationship between “community” and tools/signs towards the attainments of desired “outcomes”. While tools like AIS and digital technologies are important in shaping the mints and conditions of activity systems, the community is also determinate of the outcome of preparing each member or generation, culture, cross-cultural in accordance with their prevailing worldviews. The scientific community including STEM belongs or remains a catalyst in the transmission of scientific knowledge and skills. This often requires reform to reflect trends and in anticipation of acceptable “outcome”. Scientific ideas continue to evolve as the world and the social order concurrently change. This natural proclivity to continuously change also implies that the teaching and learning of STEM reflects the rapidity of these changes as well as the kinds of skills sets needed in contemporary times (21^{st}) using the “tools/signs” available. For instance, the invention/discovery of the wheel paved the way for the advancement in the automotive industry in the $19/20^{th}$ centuries. By understanding the mechanics and operations of the wheels, scientists (community) at that time, applied these accumulated knowledge and skills sets to retrofit it into steam engines to pump water from mines fields as this was one of the predominant economic ventures of significance. Later, these same engines were adapted and retrofitted into train engines and coaches to transport many of the minerals mined cascading in the creation of a network of transportation industries-opening up new communities and efficiency in communications and mail delivery. As Bonk noted in his insightful book, *The World is Open: How Web Technology is Revolutionizing Education* (2009), this partly laid the foundation for the emergence of universities and academics of learning through correspondence and the advancement and training of the generation of scientists. In these we see the direct correlation between an emerging portfolio of technology impacting scientific practices shaping the nature of educational practices.

Currently, there are an avalanche of AIS and digital technologies available across every culture (Bonk, 2018, 2019). The first and even the second generation of web technologies have created an information overload in the 21st century. There is an increasing traffic of scientific research and collaboration across the scientific communities using these tools. Educators are increasingly shaping and retrofitting their professional skills to remain relevant and apt to create active and relevant teaching and learning communities using 21st century tools herein AIS and digital technologies.

At the threshold of this dissertation study, there is a credible report from public health related organizations such as The Center for Disease Control (CDC), the World Health Organization (WHO), The National Institute of Health (NIH) about the outbreak of coronavirus (COVID-19) pandemic (Bloom et al., 2020; Gandhi et al., 2020; Wilk et al., 2020). Epidemiological models project that the pandemic may last many months across almost all continents. Thus, a global shutdown or restriction of movements of nonessential people ought to stay home given the mode of transmission of the pandemic. Several educational institutions simply transformed from the mortar and brick STEM educational classrooms to virtual classrooms using prevailing digital technological platforms such as Google classrooms and Jamboard, Sphero Apps, LEGO Apps, Star Walk Kids, Prodigy Math Apps, Hopscotch, and many others from K-12 to Colleges and professional institutions of higher learning and research. Undoubtedly, these AIS have greatly sustained STEM education even during the magnitude and impact of the pandemic. Of course, institutions lagging in these AIS and digital technologies are bearing the brunt of the global shutdown including loss of productivity (teaching-learning of STEM) among others. Although there have been attempts to distinguish between the kinds of skills to be acquired in education as different from the real world, our earlier discourses on the PBL debunks this presumption. Indeed, “a lot of people think the skills that students need to learn for the workforce and the skills they need to learn to be a good citizen are two separate sets. But they’re not. What makes a student successful in the global workforce will make a person successful at life" (Wegner, November 20, 2008). We saw in the discourse on activity theory that community herein, the classroom is crucial in teaching and advancing STEM education and skills. The teacher has the onerous role to promote the interests of the teaching-learning community reflective of the wider social community and sitz-im-leben. In reviewing prevailing literature on the research topic, it can be inferred that education has metamorphosed in the past century as cultural and socio-economic factors have changed rapidly especially since the 1960s (Irzik & Nola, 2009; Matthews, 2009; Mayor, 2018). Since then, artificial intelligence and digital technologies have created and shaped a digital multicultural grid. Thus the 21st century teaching and learning STEM community can be described as a digital age with a concomitant culture and skills required to be relevant and productive. Those with these skills have been described as digital natives, digital aliens, or internet generations (Irzik & Nola, 2009; Wegner, 2008). The current pods of the 21st are markedly "…multi-taskers, they are drawn to graphics, they like instant gratification, they use Web 2.0 tools to create, and they love collaboration," and "If we can figure out how to grab their interest in learning, they'll become great thinkers and be eager to learn the basics."(Wegner, November 20, 2008). Thus, the call for STEM education that is inexplicably bound with the prevailing epistemological and ontological worldviews and experience hence the 21st century skills. But what exactly are these 21st century skills? Are these teachable skills in the STEM classroom? There are diverse opinions of what constitutes 21st century skills. For instant, Wegner (2008) identifies the following clusters as 21sts century skills:

1. Problem-solving and critical thinking

2.Collaboration across networks and leading by influence;

3. Agility and adaptability;

4. Initiative and entrepreneurship;

5. Effective written and oral communication;

6. Accessing and analyzing information; and

7. Curiosity and imagination.

The National Educational Association (NEA) lists only four skills, namely,

1.Critical thinking,

2. Creativity,

3. Communication, and

4. Collaboration

The NEA consider these skills as key to teaching and learning STEM. Respondents believe that the "top three skills for educators are flexibility, knowledge of system operations, and the ability to relate to students through the lessons they are teaching." The application of AIS in STEM can fester these skills. Flexibility is key to effective teaching of STEM with an AIS. It allows a teacher to design and develop many quality STEMS lessons that can be taught in the same classroom and under different or other suitable teaching and learning conditions. Flexibility as a prerequisite to effective STEM education and in the promotion of 21st century skills. This implies pedagogical malleability as opposed to the hitherto bookish, textbook, and test-oriented teaching methods prevailing in some educational policies and practices. Using AIS in STEM educational activities imposes a kind of categorical imperative (Kant) on teachers to be open and flexible to changing their methodologies, topics and even the classroom spaces to reflect prevailing community standards or outcomes in an activity theory system. Study participants have intimated the plausibility of differentiated teaching and learning STEM classroom environments reflective of contemporary worldview and experiences. Specifically, understanding teaching and learning

STEM in the classroom in alignment with their respective worldviews and experiences of students will promote these skills.

5:7 The Pedagogical Application of AIS in Scaffolding STEM education

Scaffolding is one of the extant themes emerging from the current doctoral dissertation study. There seems to be a consensus among research participants on this. It is believed that AIS Sphero promotes and enhances scaffolding methodology for teaching and learning STEM in our schools. As one respondent categorically noted, using the Sphero "has made planning activities easier because of the ability to scaffold the learning and the ability to use them with multiple grade levels. The app and website also make it easier to assign tasks." The concept, nature, function of scaffolds is an integral part of modern theories of teaching and learning in education. The emergence of digital culture has opened a labyrinth of lens to reappraise the role of scaffolding in the teaching of STEM education. As indicated above, scaffold has emerged as an important concept inter alia the application of AIS tools in STEM classrooms during data analyses. AIS such as the Sphero serves as a pedagogical tool in mediating and advancing STEM educational activities. This is significant and worth further analysis. But what are scaffolds? Are scaffolds significant in science education? How does AIS and digital technologies such as the Sphero bolts and apps serve as tools in STEM classrooms? A dexterous analysis and responses to these questions will suffice in establishing the significant role of scaffolds in STEM education.

Generally, scaffolds are designed to serve fleeting roles during building or construction of engineering feats and architectural designs. They are often found in the form of wooden, metal, or plastic materials at varying stages of building, maintenance sites, cleaning crews, bridge designs, roofing, and many others. While scaffolds may sometimes be deemed aesthetic nuisance or obfuscate actual structures, they nonetheless serve significant roles in shaping the final projects or designs. Once their objectives are attained, the entire scaffolds are dismantled, discarded, or discontinued so that their actual work emerges in their respective grandiose and splendor. In other words, scaffolds are means to attaining an end-they are not meant to be permanent but serve as templates or springboards towards specific building or construction objectives. Pioneering scholars in educational psychology and linguistics have identified some corollary of the concept of scaffold to education especially in the teaching of STEM (Belland,2011; Lajoie,2005; Martin et al., 2019). This is often cusped in the words of Vygotsky's "zone of proximal development" (ZPD).

In one of his fastidious expositions, Vygotsky (1978) defined the zone of proximal development as: "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (p.86). He postulated the thesis that individuals or learners have the inherent disposition towards learning (potential) in view of their developmental stages. He posited that individuals would attain their full intellectual potentials if responsible adults such as teachers, competent peers, parents provide them (scaffold) with guidance through pedagogical interactions (albeit social). That is activities, skills in pedagogical settings (within their social contexts) that a student can perform on his own and the difference he cannot attain without the help of his peers, adults such as teachers (Alvarez, 1995; Belland, 2011; Cazden,1993; Daniels, 2001; Lajoie, 2005; Martin et al., 2019; Woods et al., 1976; Vygotsky,1978). This approach can be in the form of scaffolding their instructional activities so individuals can master learning objectives and ultimately discontinue the structures, so they become independent.

Hence, instructional scaffolding implies incorporating pedagogical activities such as cues, problem solving, projects so that learners acquire new knowledge or skills typically expected of them and leaving them also to independently learn at levels proper to their development (Daniels, 2001; Engeström 2007, 2018; Mwanza, 2001). While Vygotsky never used the term "scaffolding", his ZPD has become synonymous to the term. It is generally accepted that Wood, Bruner, and Ross (1976) introduced the term scaffold as a depiction of the Vygotskian ZPD into the lexicon of instructional theory or pedagogy. According to Woods et al. (1976), scaffolding or scaffolds "…enables a child or novice to solve a task or achieve a goal that would be beyond his unassisted efforts." (p.90). Cazden (1993) also expatiated on the emerging meaning of the concept and proposed a vertical and a sequential scaffold in the context of instructional activities.

In its vertical sense, Cazden postulated that adults such as educators scaffold the learning process by probing or asking learners to expatiate on what they already know. He believes these challenges learners to delve deeper in the learning process. Through sequential scaffolding such as children's routines (games, playtimes), instructions can be structured around these to enhance teaching and learning of new and even challenging concepts and skills. However, some scholars of educational theory and learning (Lajoie,2005; Martin et al., 2019; Sharma & Hannafin, 2002) have offered varying expositions on what constitutes a scaffold. According to Martin et al. (2019), scaffolds are "…as support purposefully designed and embedded within instructional materials, such as printed activities and technology tools, to help students work through complex problems (p.71) while Sharma and Hannafin (2002) see scaffold as "… the provision of technology-mediated support to learners as they engage in a specific learning task" which includes "…tools, strategies, or guides that support students in gaining higher orders of understanding" (p.29). Tools are of educational significance in STEM activity systems and spaces such as a classroom. From the functional perspectives, Hannafin et al. (1999) offers four descriptions of scaffolds that aligns with the applications of AIS such as the Sphero in STEM classrooms. For Hannafin et al. (1999) scaffolds are functionally classified as: conceptual, metacognitive, procedural, and strategic (p.118 and pp.131-134). The emergence of artificial intelligent systems has provided an important overture for scaffolding teaching of STEM in the contemporary digital multicultural grid. The current study is indicative of the role of the Sphero as scaffolding in teaching STEM. This is attainable through the provision of the Sphero bolts and apps to students during STEM activities. The instructional activities, rules for individual students as well as their respective groups helps STEM teachers to anchor students learning experiences of concepts and skills. For instance, by providing specific codes and programming language, students can use them to rewrite advanced JavaScript codes and re-program the Sphero bolts and upload this in the app. Sphero's bolts and apps help teachers design teaching, learning materials of relevance beyond the classroom because the technology serves as a scaffold to advance STEM educational activities. Here is a sample activity provided by Sphero Edu (edu.sphero.com/cwists/preview/46968).

Figure 13

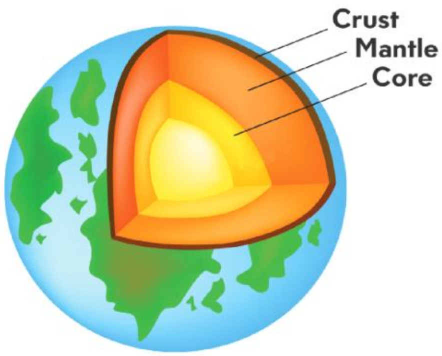
Layers of the Earth Lesson Plan

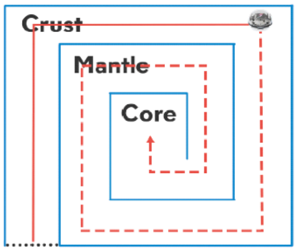
Exploration: Layers of the Earth **READ:** Humans have never actually travelled to the center of the earth, but geologists—scientists who study rocks—have used data from earthquake waves to learn a lot about the planet underneath our feet. It turns out that it isn't one big solid rock. It is made up of different layers: • **Crust:** The outermost layer and the thinnest. The lighter crust elements, such as Silica, allow the crust to float around on top of the layer beneath it. • **Mantle:** This layer is much hotter than the crust, reaching temperatures up to 2000° C. The mantle is composed of heavier elements like magnesium and aluminum. • **Core:** This layer forms the center of the earth.

In this activity, you will use Sphero's Block Programming environment to roll Sphero through a maze leading to the center of the earth. Scroll to the second image to see the maze.

DISCUSS:

- *Why do you the think inner parts of the earth are hotter than the crust?*





Challenge: Narrate Your Journey

READ:
In this step, you will insert the **speak blocks** that are already on the **Block Canvas** to narrate your robot's journey through the maze.

DO:

- Find the fact about the crust.
- Insert it into your code at the appropriate location.
- Find the fact about the mantle.
- Insert it into your code at the appropriate location.
- Find the fact about the crust.
- Insert it into your code at the appropriate location.
- Test and debug.

- When your program is working correctly, take a video of your Sphero robot completing the maze and upload it to this step.

The above sample lesson (Figure 13) exploring the topic, *Layers of the Earth* is a classic application of the Sphero bolt in scaffolding a STEM activity in the classroom. Teachers scaffold these types of STEM lessons by incorporating succinct instructions and objectives to learners. The above Sphero based lesson offers opportunities for STEM educators to challenge students to first explore the AIS (Bolt) by simply rolling it without any specific instructions. As students become *familiar* with the functions and programming language of the robots, they are then *challenged* to build their own project (independently) following the instructional directives provided to them in accordance with their ZPD or what I call the *sphere of proximal digital multicultural development.* There is evidence in the current study pointing to this assertion as some of the Sphero certified educators indicated that the technology helps *scaffold* their teaching of STEM. Because the *Sphero serves* an important educational role in the STEM activity system and in the words of Hannafin et al (1999) can "… provide the overt means through which individuals engage and manipulate both resources and their own ideas… Tools do not inherently enhance cognitive activity skills; rather, they provide a means through which thinking can be enhanced, augmented, and/or extended" (p.128). Hannafin et al. (1999) have noted further, that "tools provide vehicles for representing and manipulating complex, abstract concepts in tangible, concrete ways. …" (p.128). This is of pedagogical significance because tools are essential in activity systems. Activity theorists (Engeström, 1986, 2016; Lindqvist, 2003; Miettinen & Engeström, 1999; Vygotsky,1978) generally classify tools as physical, symbols and language. Such taxonomy of tools falls short of the emergence, advancement, and proliferations of AIS in contemporary times marked by digital culture. It is in view of this that I postulate the thesis for a *zone of proximal digital multicultural* *development* (ZPDMD). By ZPDMD, I mean digital knowledge and skills in a digital multicultural grid or worldviews. STEM educators must be cognizance of the digital competence of their learners in scaffolding instructional materials. As indicated above, learners ought to be digitally skilled and competent in basic digital modalities and computational thinking skills required in the 21st century to participate in STEM educational activities. In the context of the robots, teachers will be familiar with basic coding and programing language, blocks (speed, heading, delays, stops, roll-block) to design and accomplish their instructional module. They also must be familiar with the Bluetooth and GPS enabled features which promote advanced technological sophistication in the STEM classroom-a key component in teaching and learning. Teachers can access and understand in real time the performance of their students and give feedback as well as scaffold lessons for learners into *deeper understanding* of scientific principles and projects such as the earth and the various components such as the crust, mantle, and the core classic illustration of the *sphere of proximal digital multicultural development*. The former corresponding with the Vygotskian *sphere of proximal development* while the latter depicts the level of students independently acquiring sophisticated scientific and technological skills with the use of the Sphero AIS in STEM educational activities.

5:8 The Zone of Proximal Development and Digital Multiculturalism

Vygotsky's proposition of the ZPD has been accepted and incorporated into many educational and linguistic theories across the world (Río & Alvarez, 2007). There is an aggregated scholarship (Engeström, 1999) bolstering the thesis that AIS and digital technologies have created a new "community" or simply put, digital multiculturalism that may seem antithetical to previous educational landscapes and worldviews. This requires a critical purview, analysis, and re-appraisal of the Vygotskian ZPD to understand STEM as an activity in the 21st century given the emergence and development of AIS. Vygotsky's ZPD were formulated at a time when the dominant socio-psychological models suggested that children's ability and proclivity towards learning was unidirectional, conterminous with their chronological age and social development. These views have transcended the second and third (Engeström, 2007) generations of activity theory. Thus, the role of the teacher in an activity system (albeit education) among others is to scaffold teaching in accordance with the learner's zone of development. If the learner masters the concepts, the scaffold and teaching support and approach is discontinued to enable the learner to advance independently in the learning process. This approach also envisions the educator as an "expert" in the teaching-learning process bestowed with sets of professional competencies and skills that he impacts or teaches the learner in consonant with his development. However, some scholars (Bennett et al., 2008; Irzik & Nola, 2009; Palfrey & Gasser, 2013) postulates that learners in contemporary digital culture may have digital skills and competencies and perhaps be more versatile in AIS than educators. Indeed, some scholars have classified the current population into digital natives, digital immigrants, and digital aliens. Students and educators born after 1980 represent digital natives. Digital immigrants are those born prior to the 1980s who acquired digital competencies and skills. Digital aliens correspond with digital immigrants chronologically, except that they do not possess the same digital technological skills. Educators must align their teaching approaches with experiences and meaningful activities that reflect their digital multicultural worldviews and experiences.

In addition, empirical evidence (Bennett et al.,2008; Brynjolfsson & McAfee, 2014; Palfrey & Gasser, 2013) and the data from the current doctoral study continue to affirm the significance of AIS and digital technologies such as the emergence of a digital culture and novel skills needed in the 21st century workplace and life. I believe that a "Zone of Proximal

Development" might not necessarily apply in an era of digital cultural worldviews and experience. The concept of a "Zone of development" appears to be an epistemological speculation lacking precision. Besides, the 1G to 4 G of internet and digital technologies have created information and knowledge highways. At the threshold of the 5G of digital technological advancement, the notion of a "zone" in a child's development seems to obliterate the digital technological development and skills they possess in default in a digital world. This is even problematic as students have mastery of digital skills and AIS and appear to use these technologies even more than some of their teachers. Students in K-12 education are coding, learning programming languages, designing robotics just to enunciate a few. Teaching of STEM at home, schools ought to align with learners' digital skills and competencies rather than the teacher's skills and pedagogical competence as in current educational practices and professional reform programs. In view of this lack thereof of alignment, I propose that teaching of STEM using AIS such as the Sphero should create opportunities for learners to exhibit competencies in accordance with digital culture and skills of the 21st while the teachers' role is defined as a facilitator. In the dissertation data, respondents indicated the evolution of the role of the teacher as *a facilitator*! Since AIS and digital technologies are rapidly evolving, I propose a "digital sphere" of proximal development rather than a zone. A zone appears limiting and exclusionary while a *sphere* is expansive. Indeed, one of the definitions of a *sphere* in the Oxford Dictionary is "an area of activity, influence or interest; a particular section of society". One of the keywords here is "activity" within society. This is consistent with our operational definition of science as a social or cultural activity-in which a segment of society uses tools, artifacts, platforms and apply specific rules in pursuit of meaningful activity culminating in some form of epistemological change, new skills and products and others. The STEM educator does not necessarily represent the epitome of absolute scientific knowledge. And scientific knowledge is not and should not be constrained to some few cultures, professional groups alienated from the prevailing culture. Rather as a social activity, the STEM educator creates the opportunity for the learners to extrapolate meaning out of the application of AIS and digital technologies in the classroom. Thus, as some educators scaffold or teach STEM with AIS in their classrooms such as the Sphero, others might apply LEGOs or other forms of technologies in teaching the same topic creating and embellishing the corpus of scientific expertise and knowledge.

Also, AIS is *generative* (Brynjolfsson & McAfee, 2014; Yoo et al., 2010; Zittrain, 2006, 2008) and therefore offers a plethora of opportunities in STEM classrooms. By combining various features, platforms, and architectures, AIS can create a new corpus of STEM knowledge and products unimagined. This is also important in recalibrating the role of the teacher in a STEM classroom. AIS and digital technologies continue to create novel epistemological spheres requiring constant updating and creativity. As Yoo et al. (2010) and Zittrain (2006) and other scholars have noted, AIS and digital technologies are also by nature “combinatorial”. Hence in a STEM class, through instructional scaffolding of the teacher, learners can and do create completely new corpus of knowledge and skills hitherto unknown. It is my contention that when the “zone” is seen as a sphere, it will embody one of these unique traits of AIS and digital technologies such as the Sphero bolt. This creates a kind of *tripartite*-teaching and learning pathways. This is because the STEM educator, the student/learner as well as the AIS all contribute to the emergence of a new corpus of epistemology and skills towards the advancement of science.

Furthermore, the fourth generations (4G) of digital technologies and AIS have opened the world and connected many people in real time. This invariably has created new paradigms shifts about different cultures and their respective approaches to teaching STEM education. Until recently, educational theories and practices in the USA for instance have been inordinately saturated by Eurocentric worldview of a monoculture to the exclusion of the diversity of global cultures and their contributions to STEM and allied scholarships. Almost universally, there is a recognition of cultural pluralism or multiculturalism. There is an emerging *digital multiculturalism* that embraces the abyss of epistemologies of every nook and cranny of the world especially in STEM education. As a social activity, STEM education takes place in many forms, and cultures. There is no singular "developmental" tangent that every student (for example K 9-12 grader) ought to be or is expected to attain. The Vygotskian notion of a child learning to attain his developmental stage upon mastery appropriate tasks given him by his teacher poses some challenges in the contexts of pluralism and multiculturalism in an open society. Indeed, each culture defines their open educational expectations and policies. There is no universally acceptable developmental stage *terminus ad quem* for teaching-learning STEM. Rather teaching and learning should be perceived as a *terminus post quem in* view of a *terminus a quo*! Herein, a "sphere of proximal development" precipitated in a multicultural digital grid or worldview encapsulate the open nature of contemporary world in which scientific education is seen as a mutual exchange between teacher, learner and at the intersectionality of AIS and digital technologies in a perichoretic manner. This deconstructs (Derrida & Caputo, 2020) the euro-monocultural and unidirectional trajectory of teaching a student in accordance with a dogmatic developmental phase or level. While the Vygotskian approach appears broad, it nonetheless lacks the candor (in my opinion) of contemporary understanding of digital multiculturalism (partly created by digital culture and AIS). In other words, teaching and learning should be projected towards a multidirectional rather than unidirectional perspective. A multidirectional development goal reflects the multicultural and multidimensional nature and shape of a sphere. A penumbra of epistemological ecologies to be explored and potentially discovered. People at the other side of the *sphere* are also striving to discover and contribute their individual and collective knowledge and diverse perspectives to the global community. If teaching of STEM is considered in a perichoretic way, learning of STEM becomes a rite of passage in which all contribute knowingly or unknowingly in the creation of scientific knowledge and skills in as far as these reflect 21st century or zeitgeist. Thus, in designing lesson plans, educators may take cues of the changing trends (Kaptelinin, & Nardi, 2006; Kuutti, 1996; Lave & Wenger,1991) in STEM classroom dynamics especially the significance of AIS and digital culture as well as students' digital skills and contemporary life as the current dissertation study unveiled. It is expedient that STEM educators challenge learners to delve into the 'sphere' of diverse scientific cultural activities using AIS and digital technologies. In brief, *a sphere of proximal digital multicultural development* is a better lens to teach STEM rather than ZPD which seems limited.

5:9 AIS and the Transformation of STEM Classrooms

The COVID 19 pandemic has explicated some of the major challenges associated with the introduction of digital technology including virtual classrooms. Before the COVID-19 pandemic, there was consensus that there exists a digital divide in the K-12 educational system. While some K-12 schools had access to the internet, mobile devices for teaching and learning, and other digital technologies and AIS, others did not reflect this changing trend. According to the *Consortium for School Networking* (CoSN, 2019) which "is the premier professional association for school system technology leaders….CoSN represents over 13 million students in school districts nationwide and continues to grow as a powerful and influential voice in K-12 education", conducted a survey in 2017, 2018 and 2019 respectively. Consistently, respondents have identified "budget constraints and lack of resources" as their priority or concerns. So, while there is a need for digital infrastructure in schools, there has been a lack of investment to bridge the digital divide. This lack of progress took an axiomatic turn in the wake of the pandemic. Indeed, as Tarek Shawk, the Egyptian Minister of Education noted at a recent UNESCO ad hoc meeting, “we have made more progress with digital and distance learning in the past 10 days than in the past ten years. Without a doubt this crisis will change the way we think about the provision of education in the future” (April 14, 2020). In addition, the UNESCO ad hoc meeting also indicated that about 1.37 bn students from K-12 to colleges were affected by the recent onslaught of the COVID-19 pandemic. This singular event necessitated an axiomatic shift, obliterating the traditional brick and mortar classrooms into digital/ virtual classroom platforms such as Google Classroom, Microsoft Online Academy, Skype, Zoom, and Sphero online STEM classroom!

As school district lockdown due to the COVID-19 pandemic, a new surge in the demand for digital technologies and virtual learning has emerged. As a result of this, many school districts are providing mobile devices like iPad, tablets, WiFi and internet access to their students as well as STEM educators. New virtual classrooms have emerged on every continent. School districts in the USA for example in New York are racing against time to provide all deserving students iPads and internet access so their students (who have been caught up in the shutdown due to the pandemic to continue their studies unabated.

In a recent *Associated Press* article, Kinnard & Dale (March 30, 2020) describes a captivating scene worth noting; “students struggling to get online in a rural South Carolina county received a boost last week with the arrival of six buses equipped with WiFi, some of the hundreds the state has rolled out since schools were closed by the coronavirus outbreak. With routers mounted inside, the buses broadcast enough bandwidth in an area the size of a small parking lot for parents to drive up and children to access the internet from inside their cars”. In fact, some school districts in Los Angeles, New York have indicated the plausibility of closing until the end of the year. After all, teaching and learning is a form of cultural activity in which all participants consciously and meaningfully use available AIS and digital technologies in transforming the STEM classroom into a space for authentic mutual epistemological rigor. Online platforms such as Sphero educational applications, Google Classroom, Microsoft's Virtual Academy, Zoom, Adobe, Skype among others have suddenly emerged with some districts bridging the digital desert for the first time in the digital age across K-12. Sphero and others have continued with these initiatives by creating STEM platforms and applications where virtual STEM classes are held enabling granting both educators and students' full access to the classroom. This is reflective of digital culture. Some STEM educators are designing and facilitating outstanding virtual classes in their respective schools underscoring the significance of AIS. Students are working on virtual projects as individuals or in virtual groups in STEM and other areas of education.

While the above appears to be the rightful cultural response to the exigency posed by the pandemic, nonetheless, it has exposed the *digital divide* in the country and in the world. For instance, during the UNESCO *ad hoc* meeting in the wake of the pandemic, Mexico's Minister of Education, Esteban Moctezuma Barragán pointed out that "Only 60% of students have internet so we had to provide a mix of distance education with open TV to reach everyone'. This sentiment of a technological gap was expressed by many other countries. Surprisingly, the notion of digital divide is closer home in many US school districts than hitherto believed. Indeed, as Kinnard & Dale (March 30, 2020) further observed, "the pandemic that launched a massive unplanned experiment with distance learning has created extraordinary hurdles for schoolchildren left behind by the digital divide" (para.4). As an earlier AP article (Melia, Amy & Fenn, 10,2019) noted, over three million US students do not have access to the internet and digital technologies. Other states especially in the south such as Georgia, Arkansas are racing against the tide of the time to link their respective schools onto the flurry of digital platforms in response to the rapid trend in the proliferation of AIS and digital technologies. It is anticipated that when the pandemic fades to oblivion, policy makers vested with authority including school districts will sustain these digital technological platforms and resources in the education of the current and future pods of students. Indeed, the second research question of this doctoral study fortuitously posited: *There is an assumption that digital technology is transforming contemporary society in every facet. How does AIS tell us about how digital technology impacts STEM pedagogy?* Sphero and other AIS and digital technologies offer roadmaps to all and sundry about the dawn of a new era: digital age and the inescapable crucible it holds for the transformation of STEM classrooms in the 21st century. The era of the scroll, brick and mortar appears to be dissipating paving the way for a digital technological renaissance in transforming pedagogical sphere. Analogous to Plato's allegory of the Cave, the digital age has just emerged, but each passage of time poses onerous opportunities towards a modicum of clarity about these AIS and technologies. Undoubtedly, teaching and learning is taking place in a world that is open (Bonk, 2019), diverse, highly interconnected (Langer, 2018) and increasingly virtual marked by information overload. As educators especially in the STEM classrooms and schools embrace these novel tools, the epistemological aperture will pave the way for a cluster of creativity, transformation for the common good. Perhaps we are just at the precipice of a digital revolution marked by the emergence and development of artificial intelligent systems. Whereas well thought policies such as *No Child Left Behind* (2001) has axiomatically left many students behind in the core disciplines of education, it is anticipated that the application of AIS and digital technologies will exemplify an educational culture of teaching and learning that truly create equal opportunity and equity in the world. While many students have been left behind in the benefits and opportunities of the 1-4 generation of digital technologies, it is anticipated that the fifth generation (5 G) will bridge the lacuna.

Preliminary Conclusion

In the previous chapter, the primary data to the dissertation study were analyzed and coded in the Dedoose software suite with approaches consistent with qualitative methods as applicable to STEM education. Several themes emerged and twelve were distinct worth further discussions. These themes or concepts from the primary data became the foci of this chapter. Each of the themes were critically studied through the theoretical framework of activity theory or cultural historical theory. This led to the notion that the AIS and digital technologies have several applications and of pedagogical significance to STEM classrooms. As an exploratory research, the dissertation approach has identified key issues of significance in STEM classrooms. Indeed, as the dissertation topic indicated, *Exploring the use of artificial intelligent systems in STEM classrooms*, hence the research has been meticulous but open ended about the extent to which AIS and digital technologies impacts STEM especially in a world described as a digital world. Through the dissertation study, I have discovered that the Sphero AIS and educational portfolio have several applications of pedagogical imports to STEM classrooms: scaffolding, integrative/interdisciplinary teaching and learning of STEM, creativity and expansive learning of science, consistent in the *Next Generation of Science Standards*, computational thinking and 21st century skill, in alignment with the Vygotskian and social constructivist concept-zone of proximal development and the emergence of digital multiculturalism in contemporary times. The dissertation data and analyses has given insights into the educators' appraisal of the Sphero educational robots in their respective STEM classrooms. Their views, both desirable and in a few instances, pejorative have provided significant data and through the theoretical framework of activity theory, to extirpate the pedagogical value and importance of the proliferation of AIS in STEM classrooms at the K-12 levels. In the next chapter however, the limitations identified in this dissertation will be discussed. It is hopeful, these initial findings will both inform and form policy and praxis towards the applications of AIS in STEM classrooms to bridge the technological lacuna in educational institutions as well as the digital divide within schools and subjects' areas.

Chapter 6: Limitations and Recommendations

6:1 Preliminary Comments

There is an African proverb which states*, knowledge is like a garden: if it is not cultivated, it cannot be harvested*. The cultivation, proliferation and maintenance of a garden involves many factors for it to thrive and blossom. These factors include the selection of methods of cultivation, types of seeds, location, duration/time, and the reliance on other resources such as water and amount of natural light. The medley of these factors and the laborious processes results in the radiance and beauty of a luscious garden worth the cynosure of the community and observers. I find this metaphor analogical to qualitative method in the pursuit and the cultivation of knowledge. Qualitative research is an intriguingly meticulous scholarly exercise encompassing methods, data instruments, and other tools in the pursuit of the central questions of inquiry. It entails meticulous planning and iterations of many processes such as an IRB approval, funding, personnel, participants just to enunciate a few.

In this dissertation study, I have explored artificial intelligent systems and digital technologies in STEM classrooms with the application of qualitative method through the theoretical acuity of *activity theory* (Daniels, 2001; Engeström, 2004; Vygotsky, 1978), sometimes described as the cultural-historical activity theory (Hasan & Kazlauskas, 2014). While the design, data analysis, discussions and implications of the findings have generated substantial scholarship on the research topic, it is equally important to note that the methodology has limitations. Like the metaphor of the garden, not all the plants will be the same even if the methods for cultivation are the same or similar. It gives credence to the notion of limitations or shortcomings. So, in this chapter, I have discussed the limitations as well as some of the potential ethical issues associated with this study. While these limitations do not obliterate the research findings, nonetheless it is worth considering in view of guiding future and prospective inquiries. Limitations such as sampling or selection bias, apparent insufficient sample size, duration of the study, conflicts of interests associated with this study and scholarship at the intersectionality of the AIS and STEM. These have been reported at the first part of this chapter.

The second part of this chapter offers some suggestions for considerations on the research findings. For example, I have recommended a re-examination of the current pre-teacher and teacher preparatory programs to make computational and digital multiculturalism core components of pedagogical content knowledge and professional practices. I believe STEM teachers be part of the architectural design and potentially contribute to the building of the next generation of AIS and digital technologies as applicable to STEM educational activities. I am hopeful that both educators and learners will be part of the core decisional bodies in the selection and the determination of the educational relevance of AIS and digital technologies for their respective schools and STEM programs. The research also calls for a recognition of the current digital multicultural worldviews of learners and the need for STEM educators to scaffold and align their teaching skills in response. In addition, the COVID-19 pandemic has transformed and revolutionized the brick-and-mortar classrooms and education into virtual pedagogical spaces within a relatively short period of time. I believe that during the post-COVID-19 eras, a blended-learning environment will emerge and hopefully be sustained to reflect the zeitgeists of the 21st century classroom! Such an environment will create a labyrinth for innovative AIS and digital technologies in STEM classrooms and other science educational activities.

6.2 Sampling /Selection Bias

The recruitment and selection of subjects from a population is essential to qualitative study (Cassell & Symon, 2004; Charmaz, 2006; Creswell, 2018). Every research is unique and contingent on the nature of the research questions, objectives, location, and availability of resources to the researcher. Several proven methods are available for qualitative research involving human subjects in science education. Research involving human subjects of legal age capable of giving informed consent (Beauchamp et al., 2000; Kornyo, 2017) are important for the success and validation of qualitative inquiry. Currently, there are both local and international policies and guidelines for the recruitment of human subjects to participate in scientific research. Several events in the past has culminated in the promulgation of norms such as the Principle of Helsinki and Federal Guidelines on clinical research involving human subjects (Nuremberg Code; Belmont Report; Office of Human Research Protection (OHRP)) which obliges researchers to seek IRB approval for research involving human subjects. In this context, this dissertation study initially sought for IRB approval to conduct this research. Upon the approval of the research design and protocol by the IRB, I identified several potential STEM educators at the K-12 and collegiate levels. The researcher then identified specific characteristics of potential subjects in the population to be recruited. Recruitment flyers and emails were sent out detailing the research topic, objective, duration, potential ethical issues such as data security and privacy and others.

In view of the above, I sampled from the population of STEM educators for the research. The recruitment of subjects was determined by a corollary of factors such as the type of the research, research design including the topic or research question, availability of resources, location, among others. As Creswell et al. (2018) notes, "the concept of purposeful sampling is used in qualitative research. This means that the inquirer selects individuals and sites for study because they can purposefully inform an understanding of the research problem and central phenomenon in the study" (p.158). The research topic: *Exploring the use of artificial intelligent systems in STEM classrooms* is a significant determinant of the type of research subjects needed for the study. It focuses on specific academic areas herein STEM educational activities involving teachers, learners, administrators, policy makers and ancillary personnel. Thus, at the beginning of the research design, there arose the debate as to whether teachers, students, administrators, qualified to be recruited as research subjects. I decided to select only STEM educators, purposefully for the study with a hope of exploring and gaining insights into AIS and digital technology in STEM classrooms. I believe this initial study has laid the foundation and advance our perception, understanding as well as the role of AIS in a digital world at the K-12 level with implication for STEM educators. Despite these, the design and recruitment processes pose challenges to this qualitative study.

As the principal investigator of this study, I designed flyers, composed emails, and formulated an initial criterion for recruiting subjects deemed to be associated with artificial intelligent systems in their STEM classrooms. The intended outcome of the research has been for the current sample size to be a representative of the population of STEM educators using AIS and digital technologies in their respective classrooms. As a principle, the investigator used the *maximum variation sampling method* which according to Creswell et al. (2018)

> …consist of determining in advance some criteria that differentiate the sites or participants and then selecting sites or participants that are quite different on the criteria. This approach is often selected because when a researcher maximizes differences at the study, it increases the likelihood that the findings will reflect differences or different perspectives-an ideal in qualitative research. (p.158)

In this dissertation study, STEM educators in K-12 programs were selected. Then those certified to use the AIS and technologies were initially contacted at the pre-data collection phase. This initial pool consisted of educators at all levels (first grade to high school) using the Sphero applications with at least a bachelor's degree. This initial attempt to recruit research participants opened the pandora box of the myriads of educators using many forms of the technologies in their respective schools thus reflecting the heterogeneity of research participants about AIS and digital technologies in the STEM classroom. The research was then refined and narrowed down to only one specific application that appears to be popular among STEM educators and apparently versatile to students. I then selected *only* STEM educators using the *Sphero Robots and applications* in K-12 schools in the USA. This constituted a sample/selection bias (Creswell, 2018). The research design is thus limited because the data appears to reflect only the perspectives of STEM educators without the input of students, administrators, and educational policy makers. Sampling bias in qualitative research has been well documented and generally deemed to have potential to denigrate the reliability of the study outcome. The population sampled data if generalized may not necessarily represent and reflect the views of the population of STEM educators using AIS and digital technologies in their respective classroom at the K-12 level.

In addition, many K-12 schools in the USA did not have access to reliable digital technologies before the COVID 19 pandemic when schools moved on online/virtual (Finley, 2020). Some initial reports suggest between 20-40% of K-12 did not have reliable digital technologies. Several research findings have shown that there is a digital divide where some K-12 schools have disproportionate access to these technologies based on location, school districts, family income, Federal and State mandates, and other seemingly nebulous funding criteria. By limiting the research to only schools with the Sphero robots and app resources, the research inadvertently excluded many other schools whose STEM educators could have contributed data to the research topic. There is an empirical or evidential precedent to this research design locus *classicus* in the Truman and Dewey Presidential elections at the threshold of the telephone technology revolution. Many presidential race-pollsters used telephone (deemed the prevailing technology) for the surveys and predicted that Dewey was going to win the elections. However, Truman won decisively to the surprise of the pollsters and researchers. In a posteriori analysis of the methodology used, researchers identified one major flaw which snowballed into the error of the survey data. The telephone technology available at the time was generally deemed expensive and relatively well to do or good income earners could afford it. A huge segment of the potential voters in the population were inadvertently sampled out or excluded from participating in the surveys. The current study design bears similarities. This is because not all K-12 STEM classrooms have access to the basic technologies associated with AIS. And for those who have access, they probably have other forms of AIS technologies. Thus, the findings might not necessarily reflect the general population.

Furthermore, the Sphero bolts application have many other robots such as Sphero mini, Sphero RVR, Sphero mini soccer and Sphero SPKR suited for different profiles of STEM teachers, students, and content areas at the K-12 STEM classrooms. Each of these have unique features, suited for different subject areas such as photography and the arts. Thus, generalizing the research findings of the sample to the population potentially poses methodological flaws analogous to a truncated selection. Notwithstanding, it is anticipated that the research findings reflect or elucidates the hypothesis of this qualitative study on AIS and digital technologies in STEM classrooms.

It is worth noting that the research subjects are only STEM educators to the exclusion of students and school administrators. While this deliberate approach remains consistent with principles of qualitative methods and seems to conform to ethical norms and prevailing research practices, nevertheless the research design is flawed by not including students and other stakeholders in education. After all, digital culture transcends schools and by extension students as well. It will be of great significance to collect data from STEM students on their experience of artificial intelligent systems and digital technologies. What do students make off the Sphero bolts and apps? Do they have some experiences unique to them than their teachers? Will students' experiences be different from STEM educators? Do students have concerns about AIS and digital technologies in their respective classroom? These and other questions and concerns have not been addressed by the recent study. I believe this might require a longitudinal and a quantitative study which is beyond the scope of this research.

6.3 Insufficient Sample Size

The research is further limited due to insufficient sample size of research participants. Scholars in Qualitative research (Creswell,2018) believe that five/six subjects are sufficient for a good research and outcome that reflects prevailing population. Other scholars seem to contradict this suggestion that views of a small or insufficient sample size in qualitative research may not necessarily reflect the views of the entire population. Glaser and Straus (2017) suggest the concept of "saturation" be obtained to determine sample size. For example, in the current study, a review of the literature points to evidence that there are many STEM educators using some other forms or iterations of AIS and digital technologies in their respective schools. In some schools, the same educator may be using different AIS from different brands, companies, and typologies. AIS are by nature combinatorial often cascading in the generation and emergence of new concepts and tools of pedagogical significance. Thus, the frontier of AIS in STEM appears to be a wide abyss of population sample. The research is thus limited and insufficient with data from six sample size from a potential population of over a million STEM educators currently using AIS and digital technologies. This limitation does not however delineate the result of this study nor relegate the validity and reliability of this study merely on the preponderance of the sample size use.

In addition, research participants were narrowed down to users of Sphero robots and educational applications in the USA. It should be noted however that there are many other forms of AIS and digital technologies currently in use at many K-12 STEM educational programs other than Sphero in the USA. Some of these artificial intelligent systems include Micro Bit, *Cubelets Discovery Set*, *Engino STEM Mechanic*, *Fischerterchnick Robotics & Electropneumatics*, mBot and *Lego Education WeDo Core Set*. These AIS and digital technologies encapsulate many content areas, cross-concepts, topics, skills, and others consistent with the interdisciplinary nature of STEM. For example, Animoto and other AIS technological platforms such as Thinglink, Jamboard, and Edmodo and others allow users such as teachers, to create high quality audiovisual materials (texts, images, lab reports, data, diagrams) for STEM programs. Socrative and Kahoot are also applicable in content generation, homework, survey in real-time, game designs in STEM educational activities. These apps and technologies are diverse and user-friendly, and students can also create STEM content, projects, presentations with their mobile devices with similar and diverse features to the Sphero apps with pedagogical guidance. Both educators and learners are using these in STEM programs as well as other education related activities. For example, Edmodo is purported to have over twenty million users including teachers, educators, researchers, students, administrators, and others on its platform. These features are not very evident with the Sphero robots and applications. The research excludes these AIS and focused only on Sphero in the study thus limiting the potential divergent and unique data other AIS will have generated on the study towards a broader scholarship on the subject matter of the research.

In brief, even though the sample size may be deemed small compared to the over one million users of other AIS and digital technologies in K-12 STEM programs, the research findings and recommendations are of significance to STEM educational activities. However, it should be noted that the sample size of six is deemed sufficient for the study (Plummer 1983) such as AIS and digital technologies within the context of contemporary digital culture.

6.4 Length of Study

The initial plan was to conduct the study over at least a year across the K-12 educational sector to gain a deeper and broader insight into the application of AIS and digital technologies in STEM classroom activities. This initial plan entailed a comparative study involving an initial experimental design involving controlled, independent, and dependent variables that encapsulates STEM educators using AIS in their respective schools as well as those not applying these technologies. Such an approach will have extended the study into several years though the results will have reflected perhaps an in-depth insight into the research questions. However, a shorter qualitative study was chosen spanning at least six months. While data from such a short study is reliable, a longitudinal study will nonetheless elucidate substantial data on patterns and variables over a longer period on AIS and STEM education. Such a lengthy study has been constrained by lack of funding.

In addition, at the threshold of administering the research survey, the COVID 19 pandemic emerged. This led to a momentous disruption of educational activities including STEM programs and almost every facet of contemporary life. This partly culminated in some delays in receiving survey responses from prospective research participants as most were transforming their respective traditional classrooms into virtual ones due to the scourge of the pandemic.

6.5 Ethical Concerns

In addition, research involving human subjects requires extreme care, adherence to ethical norms and principles. Due to potential harm, researchers obtained permission from an IRB vested with the authority to do so. The research will also ensure that participants voluntarily participate in the research with an informed consent properly obtained. Data privacy and respect for the autonomy of research participants remain concerns in this study. These concerns are heightened with the proliferation of many data mining tools evidenced in many data/information breaches mostly surreptitious to the chagrin of researchers. A potential breach will jeopardize the research and obviously impact any future qualitative research involving the population sample. To ensure reliable security, data and any information collected have been de-identified and anonymized with codes and properly stored safely in accordance with current practices. This implies that upon IRB reviews and informed consent in accordance with Federal Norms, researcher obtains prevailing IRB permission as required by local authorities in conformity with the *Declaration of Helsinki* and Federal/State norms on research on human subjects.

Furthermore, the phenomenon of biases is well documented in research (Pannucci & Wilkins, 2010). There is evidence that biases are well spread in publication editorials (Goddard et al., 012; Pannucci & Wilkins, 2010), clinical and behavioral research, among others. The emerging field of artificial intelligence and digital technologies seemed to iterate biases described by Goddard et al. (2012) as *automation bias*. These biases often appear in data collection instruments used, data analysis and interpretation and ultimately the findings or conclusions of the research.

There is an emerging evidence that populations deemed vulnerable in society are being excluded from the R & D on AIS and digital technologies. This phenomenon seems to reify the old notion of discrimination and lack of equity in STEM including pedagogy and the nature of quality resources allocated in schools. This research study attempted to address this issue during the recruitment process of research subjects. However, there was a limitation associated in this research because it did not specifically address this population deemed vulnerable. Although this population may have been recruited for meeting all the criteria in the dissertation design (ultimately approved by the IRB), it is deemed a limitation due to a lack of heterogeneity. Time, the duration of the research was also limited.

6:6 Conflict of Interests

Conflict of interests typically involves human beings at different phases of research. For example, when research subjects or investigators have the appearance of benefiting from a research. This can be a tangible benefit such as financial gain, a product, a gift, career promotion and others. According to Romain (2015), a conflict of interest is "…any circumstances that create a risk that professional judgments or actions regarding a primary interest will be unduly influenced by a secondary interest" (p.124). The fact that all the participants were "Sphero heroes" creates the appearance of conflict of interest in terms of objectivity of their response to the research question. It is important to note that all research participants have been trained and certified to use the AIS referenced for this study by the Sphero educational corporation. As Romain (2015) suggested,

> it is important to recognize that conflicts of interest are usually quite legitimate activities, which on their own are neither unethical or illegal. An expert in a particular field may have a great deal to offer as an inventor, consultant, or speaker; and royalties, fees for services, or honoraria may be well deserved. (p.122)

Refreshingly, Romain (2019) also noted that "career choices, professional advancement, and time with family are each independently valued. The question that is critical with respect to conflicts of interest is whether these other professional or personal actions or responsibilities may compromise judgment with respect to a primary interest or responsibility, which in this case is to the research" (p.125). The current research participants have the disposition of a conflict of interests since the Sphero app company designated them "Sphero heroes" and have pontificated them as beneficiaries of their product (which constitute the subject of the current study). Cognizance of this, the research questions were carefully structured to mitigate this potential/ appearance of conflict of interest.

6:7 Preliminary Conclusion

Research remains formidable to academia and sometimes translates into policy formulations. Current research at the intersection of STEM and artificial intelligent systems are critical in the wake of the rapid trends in the skills and knowledge anticipated and expected of current generation of students. In this doctoral study I have attempted to explore AIS and digital technologies in STEM classrooms through the framework of *activity theory* or *cultural-historical-activity theory*. The focus was on STEM educators applying these technologies in their classrooms effectively. Through a qualitative research design approach, this study has gained and reported significant insights into the artificial intelligent systems and digital technologies such as the Sphero bots and educational applications in STEM classrooms. However, as an African proverb also notes, *where there is honey, there are bound to be ants.* In other words, limitations may often coexist or associate with good things. In this perspective, current research is limited or constrained by the sampling methodology and recruitment processes, sample size, length of the study, data analysis methods and tools, and some ethical concerns. These constraints have been discussed in the preceding paragraph of this chapter. These limitations do not devalue the quality of the research findings. It is however anticipated that the findings will serve as signposts and guidelines for future researchers in designing their respective scholarship of inquiry on the topic.

RECOMMENDATIONS

6:8 Preliminary Comments

One of the unanticipated findings in the current research is that AIS and digital technologies have created some *cultural identity*. That is a digital multiculturalism within education in a broader sense and particularly in STEM educational activities at the K-12 through to the collegiate levels. In science educational history STEM has been taught through the lens of a monoculture or as if there was only one culture. Such an approach reduces pedagogy to presenting science as a neutral subject with prejudice to other cultures and their respective ways of teaching and learning. As indicated in the preceding chapter, this has created a nexus of limiting many culturally differentiated approaches to scaffolding teaching methods that addresses the ever diversity of student's populations. The proliferation of artificial intelligent systems has created a *digital culture* that requires a culturally responsive approach to teaching. The scion of digital culture and the demands of the 21st century world has reached a point of saturation. And one of the emergent and identifiable characteristics of digital culture is *computational and digital cultural thinking skills*. Indeed, as some scholars have noted,

> multicultural education advocates the belief that students and their life histories and experiences should be placed at the center of the teaching and learning process and that pedagogy should occur in a context that is familiar to students and that addresses multiple ways of thinking. (*National Association for Multicultural Education,* n.d)

In addition, teachers and students must critically analyze oppression and power relations in their communities, society, and the world. The frontiers of teaching and learning has gravitated towards and an open-teaching-learning spaces partly attributed to the proliferation of the fourth generation (4G) of digital technologies and AIS. Cultures across the world are digitally interconnected, markedly collaborative on STEM projects in real-time and through other efficacious ways. Teaching methods in other parts of the world are converging, expressing the medley of diverse ways of teaching, and learning STEM education. Simply put, pedagogy especially in STEM activities occur in a digital culture or digital-multicultural spaces requiring a digital-multiculturally responsive computational and digital thinking skills.

In view of the above, STEM educators are increasingly under a kind of categorical imperative to be digitally literate and versatile in computational thinking skills in alignment with their digital era students. Indeed, science education as a human and cultural activity imposes a cultural imperative on STEM educators to formally acquire these skills to stay relevant in the 21st century STEM classrooms and learning spaces. There is evidence in this study that all respondents were "Sphero certified" educators or "heroes" as they are popularly known. Throughout the certification process, the Sphero educators were prepared and formally trained to acquire skills and knowledge needed with Sphero AIS and digital technology systems adept to teaching STEM and other subjects including Languages, History, Painting, Music, among others. Google, LEGO, Apple, Microsoft, IBM, and others are frontiers in this. These have created certification pathways or programs for STEM educators and students to gain competency with these tools. Apple offers diverse STEM lessons on Sphero at the introductory, intermediate, and advance levels at designated locations throughout the US for K-12 students at no costs. This gives opportunity to students to learn coding, programming, painting and photography, mathematics, physics engineering concepts such as acceleration, magnetisms, electricity, and other subjects using the Sphero robots and iPads or learner's own choice of device/platforms. Many other corporations are offering similar programs within and outside regular school curricula for educators and learners. These trends reflect the zeitgeist of the 21st century for which all and sundry including STEM educators can embrace and be part of to remain professionally relevant and effective. A STEM teachers' educational credentials and pedagogical competent knowledge is incomplete unless it is linked up and exudes AIS and digital technological competence and skills of the 21st century digital multiculturalism! It is the fervent opinion of this piece that pre-teacher preparatory programs design and align courses and training portfolios as core requirements for current pods of pre-STEM educators. In addition, professional development programs also incorporate courses and sessions towards the advancement of pedagogical content and skills at the intersection of artificial intelligent systems and digital culture for STEM educators.

Secondly, we seem to be at the precipice of the next generation of artificial intelligent systems and digital technological advancements concurrent with the emergence of the movement towards the NGSS. Indeed, the STEM reform movement has gained unprecedented national and professional attention and support, coincidentally, with the advancement of AIS and digital culture analogous to the sigmoid-function (s-curve). While previous reforms emanated from policy makers and others, educators in STEM seems to be at the epicenter of these novelties in terms of usage. It seems imperative for educators' views and suggestions to be incorporated into the development of the next generation of these standards in the context of digital culture as pervasive in our schools. But it seems educators have not been at the frontiers in the R & D including design, curation, and creation of AIS and digital technological platforms and architectures. This lack thereof or exclusion, unless reversed may become like the *assessment* market where "external" or corporations design and administer tests to students without their respective STEM educators' relevant inputs which has created unequal educational opportunities. And as several empirical studies have pointed out, some of the tests do not reflect students' worldviews including culture and diverse approach to learning. That is standardized tests do not align with teaching and learning of STEM! There is a need to tap into the pools of educator's competence and collective experiences towards the creation of these AIS and digital technologies as applicable to STEM education. Educators are competent, knowledgeable, and adept to technological innovations and creativity given the opportunities and platform to exhibit or demonstrate so. In less than a fortnight, teachers transformed most of the regular brick and mortar classroom into virtual classroom during the COVID 19 pandemic! Some STEM educators seized this zeitgeist moment to create innovative lessons virtually in STEM such as Sphero Engineering weekly courses, chemistry, mathematics, arts, and photography, among others. This historic feat precipitated by the COVID pandemic is a tacit reminder that if educators are offered the chance and resources to innovate AIS and digital technologies relevant to the STEM classroom, they can and will do so with alacrity and dexterity.

Thirdly, this study has explicated and identified the notion of the diversification of AIS and digital technologies in STEM classrooms. Obviously, diversification exemplifies and reifies the multicultural spaces in education. Learners are diverse in their worldviews, communities, use of tools, technological skills, and sophistications. This requires culturally relevant pedagogical responses. And in terms of contexts [STEM], one prominent professor of education (Emdin) postulated

> educators need to embed themselves to some extent in the communities their students live in and then incorporate elements of that community into the classroom. This goes well beyond talking with students about where they're from; it moves toward a cultural immersion in the community. It also pushes back against traditional approaches to school-community relations that focus on inviting the community to the school without going to the community. That approach sends a message to the communities that the school holds all the value and power in the relationship. (*The Seven Cs for effective Teaching,* September 2016)

Differentiated teaching methods include content, variegated lesson plans, assessment, classroom space arrangement, choice of AIS and digital technologies in response to the current diverse learners/students who are increasingly aware and operating in culturally diversified world/contexts. Teaching of STEM ought to be a cultural response to science as a cultural activity in contexts of students and current cosmological and epistemological ecologies of digital culture. Pragmatically, educators training in culture competent skills exhibiting pluralisms and diversity of digital culture to remain aligned and relevant in the 21st STEM classroom. Science is simply a cultural activity that occurs in a context. Educators must not be aversive of these contexts and but be culturally and pedagogically responsive in STEM classrooms.

In addition, the notion of diversity is seen in the existence of many AIS and digital systems nifty to STEM education. Because contemporary classrooms are diverse as AIS, it is recommended for the consideration of STEM educators to diversify these tools. For example, in teaching about cells, a STEM educator can create diverse lesson plans; one lesson plan around Sphero bolts; one around LEGO AIS systems and another around 3D printers as projects for each respective group in the same class at the same time. The Sphero can be programmed to model animal cells in the classroom with each project group member responsible for an aspect. The LEGO AIS group can also model living cells while the third group can translate these models and bioprint the cells with the 3D printer in the classroom connected to the Sphero apps. Each of these offer diverse and unique experiences for learners as in the real world satiated with diverse digital cultures. It is important for STEM educators to embrace emergent and diverse technologies through professional immersion and training programs reflective of these trends and cultures.

Fourthly, blended-teaching-learning, or virtual classrooms have emerged with the help of AIS and digital technologies. Tutoring systems, e-labs and libraries have all existed prior to the recent COVID 19 pandemics. Currently, almost every social institution such as commerce (banking, shopping, billings), medicine (telemedicine), religion and worship, and education have migrated into virtual classrooms. While many school districts have had comparative digital and AIS technological privileges, many students experienced the antithesis. Fortuitously, at the peak of the pandemic in 2020, almost all traditional classrooms evolved and metamorphosed into virtual classrooms on platforms or massively virtual learning management systems (MVLMS) such as Google Classrooms, Zoom, Blackbaud, Canvas, Schoology, Socrative just to mention a few. Indeed, this is a technological tsunami of historic proportion with ripple effects still dissipating in the world of education. Almost all educators including STEM have gone online irrespective of teachers' competence in these technologies. Juxtaposing this rapid transition with the current dissertation study it has become apparent that Blended or Virtual Classrooms are retained post-COVID 19 digital worlds. This study projects that eventually STEM classrooms could reflect a digital world, the current leap towards this necessitates some reflections about the preparation, training and equipping the next generation of educators in relevant AIS and digital technologies. Virtual classrooms are no longer privileges for a few in education hence the need to demythologize such a notion and create an open STEM teaching and learning spaces and contexts. It is hopeful that additional research will be conducted on teachers' views, experiences about their current use of AIS and digital technologies during this global virtual classroom phenomenon. This will elucidate which aspects of these technologies are pedagogically relevant, adaptable, or malleable to STEM classrooms of the 21st science educational activity systems.

In addition, it is recommended that STEM educators create opportunities for

> co-generative dialogues—or *cogens*—[which are] are structured exchanges in which students and their teacher co-develop strategies for instruction that focus on the students' socioemotional and academic needs. The dialogues enable open

communication concerning both the teacher's and students' perspectives on schooling. (Emdin, 2016)

Future STEM pedagogical opportunities can be created on or around cogens or co-generative dialogue models. As the concept suggests, educators can co-develop strategies with students by focusing on which AIS and digital technologies that works for them in STEM classrooms reflective of their needs. For instance, the *Sphero Specdrum* rings and apps can create music by converting colors of the AIS into sound. STEM educators can create Hip hop STEM clubs or project groups within the school or STEM classrooms involving students in a co-generative (Emdin, 2016) approach to teaching or co-production (Jasanoff, 2004) of knowledge herein STEM.

Fifthly, materials either tangible or as signs/symbols are significant in activity systems such as education and STEM classrooms. As schools have gone virtual, it is equally important to reflect on the typologies of materials being used to teach STEM in the context of changes going on currently. It is anticipated that after the penumbra of the virtual phenomenon dissipates, a realistic appraisal is made about some of the changeable and unchangeable materials and spaces required in STEM classrooms. Formal and informal education have emerged, evolved, and advanced around stones, papyrus, slates, papers and in contemporary times computers, mobile devices such as phones, tablets, iPads just to enunciate a few. Digital culture has created a repertoire of digital spaces and tools such as digital technologies, e-libraries, e-textbooks, e-laboratories, digital tutoring systems and other AIS platforms and architectures. These artificial intelligent systems and digital cultures have certainly created a precipice towards replacing the traditional classroom settings of textbooks, physical labs, libraries, and classrooms in teaching STEM. Institutions do not change per se nor adept to embrace change rapidly. There is empirical evidence to buttress this assertion especially in the context of the proliferation of AIS and digital technologies. Through professional bodies such as NSTA, NSF and teachers' unions and others, in conjunction with school districts, educators can create these changes at their local or department levels in designing, producing STEM materials including apps, digital platforms and other AIS; e-books and content to replace, augment or blend with the traditional materials in our educational system.

In brief, in this dissertation study, I have identified and discussed some limitations as reported in this chapter. The research has made some recommendations based on the findings emanating from the data. I am however of the opinion that these limitations constitute an oasis of research opportunities for future inquiry and study rather than an obfuscation of the research findings.

Conclusion

In chapter One of this dissertation study, I have reviewed prevailing scholarship and available literature on the research topic. The epistemological questions and significance were discussed in view of the pervasive and proliferation of AIS in a digital culture. One of the points of departure is that technology abound in every culture, and empirical evidence across each epoch attests to this (Bridgman & Streeter 2000; Engeström, 1987). However, each culture uses technology in accordance with their sitz-im-leben or cultural milieu and unique challenges as well as social construct. In contemporary times, technology in the form of artificial intelligent systems and digital technologies have emerged and apparently diffusing and concurrently transforming every labyrinth of society including the field of education and implicitly STEM. Key concepts and terms such as, artificial intelligence, artificial intelligent systems, technology, digital technologies were discussed. Unlike other technologies, AIS and digital technological effects are rapid, generative, combinatorial, flexible and can often re-create and re-emerge into new products and applications, and platforms of pedagogical significance to STEM education. Hence this dissertation study analyzed and studied how AI technologies could transform and enhance teaching and learning of STEM in contemporary digital multicultural world.

In view of these, the latter part of the first chapter reviewed the literature on digital culture and worldviews and the significance it has on STEM. There is a relationship between teachers' epistemological import or significance of teacher's worldviews/perceptions on their professional practices and students. I am of the fervent belief that an understanding of how these worldviews especially of the 21st century students in a digital world perceive and use artificial intelligent systems can transform the STEM classrooms. In the final part of this chapter, I have identified some of the prevailing AIS in use across schools in the USA. Flurries of AIS are currently in use in STEM classrooms such as the Micro Bit, LEGO, Sphero robots just to enunciate a few. I have chosen the Sphero educational robots and applications in STEM classrooms as an exemplar of AIS to conduct this qualitative study.

In the second chapter of the dissertation study, I have identified and expatiated on *activity theory* (AT) or *cultural-historical activity theory* (CHAT) as a conceptual framework to interrogate the research topic. I have noted in the first chapter that human culture is dynamic and prevailing technologies have significance on all aspects of society. It was also noted that science is a human and therefore social activity. Every known social activity occurs in specific loci and conditions including teaching and learning spaces such as the classroom. Consistent with the constructivist theory, proponents of CHAT theorized that teaching and learning occurs when students learn at their developmental levels within an appropriate pedagogical framework or in Vygotskian terms, *zone of proximal development*. In this chapter, the dissertation examined the teaching of STEM as a social/cultural activity with prevailing tools and technologies such as AIS. As some scholars, Blin & Munro (2007) have noted, "…activities are collective and motivated by the need to transform an object, which can be material or ideal (e.g. a problem or idea), into desired outcomes" (p.477) through the mediation of tools, artifacts in an activity system such as the 21st century STEM classroom. There is empirical evidence that several AIS of pedagogical significance exists and some are in use in some STEM classrooms at the K-12 levels. Both educators and learners are using these technologies at various phases, fora, and contexts in view of STEM education. In some school districts, policy makers and educators are making some reforms gesticulating towards the application of AIS into their classroom. It should be noted that in some situations, some educators resist or may not be open to incorporating AIS in their STEM classrooms. One of the objectives of this dissertation was to inquire into the use of AIS in STEM classrooms to get some insights into this conundrum.

In the third chapter, I offered a description of my research method for the dissertation study. The dissertation is a qualitative research in view of two questions. The focus was on Sphero educational robot certified users currently at K-12 levels. After initial sampling, researcher contacted participants during the pre-data collection phase. Upon IRB approval, researcher communicated with the research participants. Informed consent dossier was signed, and six volunteers later participated in the online survey through Qualtrics and emails. The data (from five of the participants) was textually analyzed (macros enabled) and coded initially in the Dedoose software suite. As themes emerged, I re-coded, coalescing these into clusters of twelve themes. Seven themes were extrapolated and analyzed in alignment with the theoretical framework as found in the third chapter of this dissertation study. Seven theoretical frameworks were formulated out of these initial data analyses. In the fourth chapter, I discussed my findings of the dissertation research based on the empirical data extrapolated from the data analysis chapter.

One of the formidable thinkers of all times, Heraclitus purportedly stated '*there is nothing permanent except change'*. This aphorism aptly offers a glimpse into the rapid nature of the development of artificial intelligent systems in the last few decades. Analogous to the S-curve concept in technological development and management, AIS have advanced with many applications in various phases and facets of contemporary life including education, social-organization, security, R & D, healthcare, autonomous vehicles and engineering and a quagmire of others. Educational institutions all over the world appear to be meticulously attentive to the myriads of applications of AIS and digital technologies to pedagogical practices, research, learning, and assessments. The current doctoral dissertation study considers STEM as a social activity involving the thoughtful exploration of nature, phenomenon, concepts or the development of a product, technology through the applications of relevant localized tools in the discovery process. Hence through the aperture of activity theory (AT) or cultural-historical activity theory (CHAT), the dissertation examined the significance of AIS and digital technologies in STEM classrooms in contemporary times. As a social and cultural activity, science takes place both in educational contexts and outside of the scope and times of school structures.

In chapter four, I have noted that the data and analysis of the dissertation research has led to the conclusion that AIS if harnessed, has significance in teaching and promoting STEM educational rigor. Research participants using some form of AIS (Sphero robots and applications among others) have offered their insights about the pedagogical significance of AIS in advancing STEM education especially at this juncture and threshold of implementing the NGSS and other STEM programs in the USA. AIS promotes critical thinking and computational thinking skills, creativity, and independent problem-solving skills in STEM educational activities. It also improves PBL teaching methods. These appear to be consistent with the NGSS especially as many of the current students and future will be deemed digital natives and reflects the increasing demands from employers and industries about the need to have a workforce versatile in 21st century skills in ensuring productivity and the ever-changing trends in a digital world. Recent world events such as the COVID-19 pandemics at the threshold of completing this study in extraordinary ways reiterates the need to incorporate AIS and digital technologies as core features and structures of education. Almost globally, education including STEM classrooms went virtual while administrative protocols and school management caved in the same way. As we all wait for a return from virtual classrooms to the traditional brick and mortar classrooms (blended-teaching-learning spaces), there is a sense of curiosity and euphoria as to which aspects of virtual or digital classroom practices of STEM driven by AIS will be retained and to what extent could these have impact current and future STEM classrooms activities. These and other persistent questions are beyond the scope of this study. Perhaps a quantitative and further longitudinal study using other methodologies may be useful to elucidate the significance of AIS and digital technologies in STEM classrooms. Akin to Plato's *Allegory of the Cave*, it seems we are making progress in aligning AIS with STEM education for digital natives. As they progress in their educational ladder, new and even advanced forms of AIS will emerge in tandem with their progress. Perhaps, and indeed as the empirical evidence shows, AIS and digital technologies have significance in STEM classrooms if intentionally implemented and sustained. I have discussed the themes identified above through the lens of the theoretical framework of activity theory making the case for the significance of AIS and digital technologies in STEM classrooms in chapter five.

Research is a dynamic process that remains often open-ended, with the objective of gaining insights, understanding human phenomenon, concepts, principles in nature, and many others. It is not a "search" but a "research". The former entails a peripheral action whereas the latter requires a systematic, formal inquiry with identifiable methods and analytic tools within specific loci and time framework. Qualitative research methods are laborious, systemic, and sometimes laden with many limitations (Creswell, 2018; Taylor et al., 2016). Throughout this dissertation study, many limitations were encountered despite the efforts to mitigate them. In chapter six, some of these limitations were identified and discussed. While these limitations do not necessarily obliterate the research findings, they are however worthy of note as they guide and shape future inquiries on AIS and digital technologies in STEM classrooms. These limitations in the current dissertation include the following: sampling or selection bias, apparent insufficient sample size, duration of the study and some of the ethical issues such as conflicts of interests associated with this study will contribute to the scholarship at the intersection of the AIS and STEM education.

In brief, scholarships in science, technology, engineering, and mathematics have contributed to human progress, creation of wealth, increase the quality of health, food security, water, the arts and entertainment and emergent distinct cultural identity across every known human civilizations and epoch. The study of STEM always occurred within specific cultural loci formally in educational institutions such as schools, research institutes informally in extra-curricular spaces. In recognition of this approach to STEM, this dissertation considers the study of science as a cultural activity with its own distinct history and methodologies. As individuals and groups participate in these collective cultural activities herein studying science, we do so by making use of tools, symbols available and these eventuates specific outcomes of significance to social progress, cohesion, and cultural identity. Technology is at the backbone of human progress shaping individual and collective cultural activities. Technology indeed drives scientific inquiry and vice versa. This dissertation has explored a medley of human activity and participation in the advancement of science in the world.

In reviewing the literature of this dissertation, empirical evidence shows that the concept of artificial intelligence has indeed diffused and permeated every known documented culture. While the actual translation of these concepts into tangible realities differed according to individual cultural activities and loci, the 20th and 21st centuries have seen technological feats of unprecedented proportions, respectively. In addition, digital technologies emerged and permeated every fabric of society. The juxtaposition of these artificial intelligent systems and digital technologies have created a paradigm shift with a digital cultural identity of educational significance. Of interest is the proliferation of artificial intelligent systems and digital technologies impacting communication and information technology, biomedicine, commerce, security, transportations, entertainment and obviously science educational activities. Concretely, AIS are found in several human activities; AI autonomous vehicles, IBMs AI supercomputers in big data analysis and modelling, telemedicine, bioprinting and biofabricator in biotechnology, learning management systems, adaptive tutoring systems such as Jill Watson and many others. As other areas of society participate in these novel cultural activities using AIS and digital technologies, pedagogical practices and other educational stakeholders have also taken keen interest. The pursuit of science and technology are inexplicably linked to human progress. It also reifies the intrinsic proclivities of individuals and cultures to understand the natural world as they make use of what exists in their cultural purviews towards their advancement and improvement in their specific cultural loci. Tools and technologies provided important avenues in pursuing and shaping these natural traits and curiosities. For example, during the iron age, human cultural activities around this era led to the emergence and creation of metallurgical products, artifacts, building materials, household items and others on large scales. The modern era markedly transformed human culture through several cultural activities in areas of scientific scholarships and technological feats.

Contemporary society is undergoing rapid changes due to artificial intelligent systems and digital technologies. This has also created a digital multicultural grid. The dissertation study dexterously explored the use of artificial intelligent systems in STEM classrooms with a focus on the Sphero educational robot and applications. The findings have been dissected and discussed in this study to offer insights into the impact of these technologies towards the advancement of STEM education if properly used by teachers. AI technologies are opening new artesian wells for strategic educational opportunities. It is anticipated that the findings of this dissertation study will retrofit, form, and inform policy and praxis as well as create distinct theoretical basis towards the advancement of a rigorous STEM education and pedagogical calisthenics reflective of the times.

Undoubtedly, we are in a digital age under the aegis of artificial intelligent systems and digital technologies. Can the application of AIS in classrooms align with current pedagogical practices in advancing STEM education? This qualitative research might have just opened the Pandora box on the use of artificial intelligent systems in STEM classrooms through the theoretical lens of activity theory in a digital multicultural worldview. If indeed, there is any iota of truth in the aphorism, *techna impemdi nationi* (loosely translated as; technology uplifts nations), then the proliferation of artificial intelligence and digital technologies are poised to transform the domains of STEM. This might also affect theories of teaching and learning as well as other areas of pedagogical domains such as content, curriculum, assessments, among others. While the COVID-19 pandemic has given a new impetus towards the pedagogical applications of myriads of artificial intelligent systems and digital technologies to teaching and learning of STEM in contemporary times, I hope this is sustained. STEM educators versatile and skilled in the use of artificial intelligent systems and emerging technologies will in no doubt be competent in preparing the current and future scientists with computational thinking skills, critical thinking, integrative among others needed in a digital world. And as I have noted earlier, *the times are changing, and we change in them*. As these technologies are elucidating and creating new frontiers of pedagogical calisthenics in teacher preparatory programs as well as STEM educational activities. It is anticipated that students, educators, and other members of educational communities interact with digital and artificial intelligent tools, our STEM classrooms will transform desired objects and goals into meaningful teaching and learning outcomes that reflect contemporary digital multiculturalism. I believe this dissertation study will be of significance to teacher preparatory programs especially amid the introduction of the *Next Generation of Science Standards* at the K-12 levels in the United States educational systems. In brief, the proliferation of artificial intelligence and digital technologies have created a distinct pedagogical repertoire for STEM teachers.

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Appendix A

This is the official IRB letter of approval for the dissertation research.

Attachments:

- Informed Consent Form IRB 20-187 PDF Version 02-13-2020
- Expedited Review Approved by Chair - IRB ID: 20-187.pdf

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Teachers College IRB *Expedited Approval Notification*

To: Emmanuel Kornyo
From: Myra Luna Lucero Research Compliance Manager
Subject: IRB Approval: 20-187 Protocol
Date: 02/13/2020

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has given full approval to your study, entitled "*Exploring the use of an Artificial Intelligent System in a STEM Classroom* ," under **Expedited Review** on 02/13/2020: Category (7) Research on individual or group characteristics or behavior

The IRB Committee must be contacted if there are any changes to the protocol during this period. Under the new IRB regulations, continuing review for this study is not required. If you encounter any problems or issues, please contact the IRB office to discuss. When you have completed the study, please terminate using the "Terminate Protocol" button at the top of the view protocol page in Mentor IRB. The IRB number assigned to your protocol is **20-187**. Feel free to contact the IRB Office (212-678-4105 or irb@tc.edu) if you have any questions.

Please note that your Consent form bears an official IRB authorization stamp and is attached to this email. Copies of this form with the IRB stamp must be used for your research work. Further, all research recruitment materials must include the study's IRB-approved protocol number.

As the PI of record for this protocol, you are required to:

- Use current, up-to-date IRB approved documents
- Ensure all study staff and their CITI certifications are on record with the IRB
- Notify the IRB of any changes or modifications to your study procedures
- Alert the IRB of any adverse events

You are also required to respond if the IRB communicates with you directly about any aspect of your protocol. Failure to adhere to your responsibilities as a study PI can result in action by the IRB up to and including suspension of your approval and cessation of your research.

You can retrieve a PDF copy of this approval letter from Mentor IRB.

When your study ends, please visit the IRB Mentor site. Go to the view protocol page and click on the "Terminate Protocol" button at the top.

Best wishes for your research work.

Sincerely,
Dr. Myra Luna Lucero
Research Compliance Manager
IRB@tc.edu

Appendix B

This is the Informed Consent document.

TEACHERS COLLEGE
COLUMBIA UNIVERSITY
525 West 120th St. New York, NY 10027
212-678-3000 | www.tc.columbia.edu

INFORMED CONSENT

Protocol Title: *Exploring the use of an Artificial Intelligent System in a STEM Classroom*
Subtitle if needed: Interview Consent
Principal Researcher: Emmanuel A. Kornyo, Graduate Student
240-898-8625 eak2189@columbia.edu

INTRODUCTION
You are invited to participate in this research study called "*Exploring the use of an Artificial Intelligent System in a STEM Classroom.*" You may qualify to take part in this research study because you are a certified Sphero Educational Robots and applications STEM teacher and you are over 18 years old, have taught for a minimum of two years with at least a Bachelor's degree. The study is restricted to only teachers in Science, Technology, Engineering, and Mathematics (STEM) and no student will participate in this study. If you are presently participating in another study you can be part of this study.

A maximum of fifteen people will participate in this study. There are two surveys to be completed. The first survey will take one and half hours of your time to complete as soon as you submit the Informed Consent Form electronically. The second survey will take thirty minutes.

WHY IS THIS STUDY BEING DONE?

This study is being done to determine the significance of artificial intelligent systems (AIS) and digital technologies and how these could transform and advance teaching and learning of STEM.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY?
If you decide to participate, the primary researcher will:

- Ask you to complete twenty online survey questions. On the survey, you will be asked to respond to questions about your teaching role with robots and applications in STEM. For example: how did you integrate Sphero Educ Robot apps into your STEM program? During the survey, there will be periodic attention checks to ensure you are paying attention to the survey questions. If you do not pass these attention checks, your data will not be used in the study.
- Ask you to fill out an online survey about your future educational and professional plans.

These procedures will be done online through Teachers College Qualtrics Survey links and at a time that is convenient to you.

WHAT POSSIBLE RISKS OR DISCOMFORTS CAN I EXPECT FROM TAKING PART IN THIS STUDY?
This is a minimal risk study, which means the harms or discomforts that you may experience are not greater than you would ordinarily encounter in daily life while taking routine physical or psychological examinations or tests. However, there are some risks to consider. You might feel

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embarrassed to discuss problems that you experienced in using the artificial intelligent systems in your school. You do not have to answer any questions or share anything you do not want to talk about. You can stop participating in the study at any time without penalty. You might feel concerned that things you say might get back to your supervisor. Your information will be kept confidential.

The primary researcher is taking precautions to keep your information confidential and prevent anyone from discovering or guessing your identity, such as using a pseudonym instead of your name and keeping all information on a password protected computer and locked in a file drawer. Your email address (or personal identifiers) will be stored separately from the data. Your name or other personal identifiers will not be made public and will be kept confidential.

WHAT POSSIBLE BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY?
There is no direct benefit to you for participating in this study. Participation may benefit the field of artificial intelligence, digital technology, STEM education and teacher preparatory and professional development programs.

WILL I BE PAID FOR BEING IN THIS STUDY?
You will not be paid to participate. There are no costs to you for taking part in this study.

WHEN IS THE STUDY OVER? CAN I LEAVE THE STUDY BEFORE IT ENDS?
The study is over when you have completely responded to the survey questions. However, you can leave the study at any time even if you have not finished.

PROTECTION OF YOUR CONFIDENTIALITY
The primary researcher will keep all written materials locked in a desk drawer in a locked office. Any electronic or digital information will be stored on a computer that is password protected. There will be no record matching your real name with your pseudonym.

For quality assurance, the study team, the study sponsor (grant agency), and/or members of the Teachers College Institutional Review Board (IRB) may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law.

HOW WILL THE RESULTS BE USED?
The results of this study will be published in journals and presented at academic conferences. Your identity will be removed from any data you provide before publication or use for educational

purposes. Your name or any identifying information about you will not be published. This study is being conducted as part of the doctoral dissertation of the primary researcher.

WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY?

If you have any questions about taking part in this research study, you should contact the primary researcher, Emmanuel A. Kornyo or at eak2189@columbia.edu. You can also contact the faculty advisor, Prof. Christopher Emdin at emdin@icloud.com or 917-703-0261.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at 212-678-4105 or email IRB@tc.edu or you can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 10027, Box 151. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.

PARTICIPANT'S RIGHTS

- I have read the *Informed Consent Form* and have been offered the opportunity to discuss the form with the researcher.
- I have had ample opportunity to ask questions about the purposes, procedures, risks and benefits regarding this research study.
- I understand that my participation is voluntary. I may refuse to participate or withdraw participation at any time without penalty.
- The researcher may withdraw me from the research at the researcher's professional discretion if there is a breach of confidentiality of the study.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue my participation, the researcher will provide this information to me.
- Any information derived from the research study that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- I should receive a copy of the Informed Consent Form document.

Click "I agree," if you want to participate in this study. By clicking "I agree," you also confirm you are a certified Sphero Educational Robots and applications STEM teacher and you are over 18 years old, have taught for a minimum of two years with at least a Bachelor's degree.

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Institutional Review Board
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Consent Form Approved Until: No Expiration Date

Appendix C

This contains the main Research and the Survey Questions

Protocol IRB ID: 20-187
Protocol Title: *Exploring the use of an Artificial Intelligent System in a STEM Classroom*
Subtitle if needed: Interview Consent
Principal Researcher: Emmanuel A. Kornyo, Graduate Student

1: Research Questions:

I. *Given that artificial intelligent systems* and *digital technologies* have been applied in STEM educational domains (content, pedagogy, student learning, assessment). How does the application of AIS and digital technologies impact pedagogy *in STEM educational activities*?

II. Given that digital technology is transforming contemporary society in every facet. How/What does AIS tell us about how digital technology impacts STEM pedagogy?

2: SURVEY/INTERVIEW QUESTIONS

1) *Given that artificial intelligent systems* and *digital technologies* have been applied in STEM educational domains (content, pedagogy, student learning, assessment). How does the application of AIS and digital technologies impact pedagogy *in STEM educational activities*?
2) Given that digital technology is transforming contemporary society in every facet. How/What does AIS tell us about how digital technology impacts STEM pedagogy?
3) How did you integrate AIS such as the Sphero Educ Robot apps into your STEM program?
4) What were your reasons in your choice and application of AIS in your STEM educational activities?
5) Has the use of the Sphero technology made STEM educational activities easier or more challenging?
6) Describe some of the limitations of Sphero Educ Robots in your STEM educational program in your respective schools
7) How would you describe students' responses to the introduction and pedagogical application of Sphero Educ Robots into their STEM educational activities?
8) There is an assumption that digital technology is transforming contemporary society in every aspect. How does this assumption apply to the domain of pedagogy in *STEM educational activities* in the context of the application of Sphero Educ robots and apps?
9) In which educational domains do you see digital technological transformation most in your STEM program/school?
10) How will you describe teaching and learning of STEM *before* and *after* the introduction of the Sphero Educ Robots?
11) How does the presence and application of artificial intelligent systems in your STEM educational activities reflect the changing trends and culture of contemporary life?
12) In what ways does Sphero Educ robot *integrate* the disciplines in STEM?

13) What did you consider during the preparation of Sphero based STEM lessons?
14) Were the Sphero STEM lessons teacher or student based?
15) What was your role *during* the Sphero based STEM lessons?
16) What kind of assessments did you use to evaluate Sphero Educ based STEM curriculum?
17) How does digital culture create or sustain equity in STEM education in view of your experience of AIS such as the Sphero Educ Robots?
18) One of the key indicators of an educator, *pedagogical content knowledge,* is defined as "…. teachers' interpretations and transformations of subject-matter knowledge in the context of facilitating student learning" (Shulman, 1986). To what extent did the application of Sphero impact *pedagogical content knowledge* as a STEM educator?
19) Reflecting on the use of the Sphero artificial intelligent system as a pedagogical tool, what three top skills will you consider as necessary for 21st century STEM educators?
20) What ethical issues do the application of AIS and application pose to STEM education?

Appendix D

Second Survey Questions: Professional Development

1. How many years have you taught in your current school?
2. How many years have you taught as a teacher?
3. What is your highest academic attainment?
4. One of the key indicators of an educator, *pedagogical content knowledge*, is defined as "…. teachers' interpretations and transformations of subject-matter knowledge in the context of facilitating student learning" (Shulman, 1986). To what extent did the application of Sphero transform pedagogical *content knowledge* as a STEM educator?
5. How would you describe your classroom communication and organizational style?
6. How will you describe a STEM educator in a digital age?
7. Describe your professional development goals (both short and long terms)?
8. How would describe some obstacles to your professional development (STEM education)?