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A Comparative Study on Artificial Intelligence Curricula

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Abstract

This research is a comparative analysis of four K-12 AI curricula to recognize and interpret their basic elements and pedagogical approaches. Guided by (socio) constructivist and constructionist theories as the theoretical framework, qualitative document analysis is applied as the research methodology. Schwab's four commonplaces serve as the initial analytical framework. A (socio) constructivism and constructionism lens is also used to compare the curricula. The major findings are 1. The four curricula are different in their coverage of subject matters with the curriculum from the UK covering the widest and most balanced range of subject matters. 2. The four curricula apply, to different extent, student-centered (socio) constructivist and constructionist pedagogical approaches. The curriculum from the US fits best for constructionism, while the curriculum form India is most inclined to use traditional approaches. This study will form part of the data on AI educational practices useful to educational researchers, practitioners, and governments.

Keywords

artificial intelligence, curriculum, K-12, (socio) constructivism, constructionism, document analysis

Summary for Lay Audience

This research is a comparative analysis of four K-12 AI curricula to recognize and interpret their basic elements and pedagogical approaches. Guided by (socio) constructivist and constructionist theories as the theoretical framework, qualitative document analysis is applied as the research methodology. Schwab's four commonplaces serve as the initial analytical framework. A (socio) constructivism and constructionism lens is used to compare the curricula. The major findings are:

1. The four curricula converge and diverge in their basic elements. First, the curricula form Canada and India emphasize technical subject matters, while the curriculum from the US stresses social and ethical aspects. The curriculum from the UK covers the widest and most balanced range of subject matters. Second, all four curricula are student-centered. The curriculum from the US offers the students the greatest opportunities to learn by doing; the curriculum from Canada offers the teacher the greatest pedagogical freedom. Last, the curriculum from Canada stresses social environment while the curriculum from the UK stresses teaching tools and materials as their milieux.

2.The four curricula apply, to different extent, student-centered (socio) constructivist and constructionist pedagogical approaches, such as project-based learning, activity-based learning, inquiry-based learning, cooperative learning, and experimental learning. The curriculum from the US fits best for constructionism, while the curriculum from India is most inclined to use traditional approaches with an emphasis on programming.

These AI curricula provide educators and researchers meaningful and valuable examples to use, study and learn from. This study is significant in that it can form part of the existing evidence about interpreting AI educational practices to educational researchers and practitioners in AI curriculum study and design. Also, this study will be valuable to governments in educational policymaking as it provides a comparative analysis of current K-12 AI curriculum.

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Chapter 1

1 « Introduction »

This research intends to provide a comparative analysis of four selected Artificial Intelligence (AI) curricula for K-12 from different countries to look for the similarities and gaps in their basic elements and pedagogical approaches and to interpret them through the lens of (socio) constructivism and constructionism. The potential formation of AI as a school subject imposes the study of the basic elements of existing AI curricula and the evaluation of their pedagogical approaches which involve the "interactions between teachers, students and the learning environment and the learning tasks" (Murphy, 2009, p. 35). In education, a curriculum can be broadly defined as the totality of student experiences that occur in the educational process (Kelly, 2009). Although there are many different categorizations of curricula according to various standards, broadly construed, curricula can be categorized onto three levels: "the institutional, the programmatic, and the classroom" (Deng, 2011, p. 546). According to Doyle (1992), an institutional curriculum is an "abstract model" pertaining to "broad goals and general experiences" (p.487). The institutional curriculum could be an abstract idea or policy regarding what should be taught, how and why, in response to cultural and social changes. The programmatic curriculum focuses on transforming abstract institutional curriculum into more concrete curriculum forms such as school subjects, courses of study, programs (Doyle, 1992). The programmatic curriculum usually takes the form of "curriculum documents, syllabi, textbooks, and the like" (Deng, 2011, p. 547). According to Deng (2011), constructing school subjects or courses of study involves selecting and arranging "content (knowledge, skills, and dispositions)" (p. 547) and connecting the content with both institutional expectations and the teaching and learning activities. The classroom curriculum is characterized by a cluster of events and activities developed within a particular instructional context (Doyle, 1992). Based on the above definitions, it is crucial to explore the curriculum content with respect to the three levels of curriculum-making in order to better understand the nature of AI as a school subject for K-12. The institutional level of the curriculum can be inferred from the general philosophy sections of some selected curricula. The Programmatic level of the curriculum can be inferred from the content sections (guidelines, instructions, and assessments) of some selected curricula, and the classroom level of the curriculum can be inferred from the activities, lesson plans, and scripts sections of some selected curricula. The curricula to be analyzed in this study fall on different levels of these three levels of the curriculum, which will be discussed further in Chapter 5. Below is the rationale of the study which includes the context of the research, its location in the field of educational studies, and the research questions.

1.1 « Research Context: History of Research on AI »

The history of AI can be traced back to antiquity, with stories, myths, and rumors of artificial beings endowed with human-like intelligence or consciousness by master craftsmen. The field of AI research officially started in 1956 at a workshop at Dartmouth College, where the term "Artificial Intelligence" was coined by John McCarthy (Russel & Norvig, 2010, p. 17). The Dartmouth Summer Research Project defined AI as the issue of "making a machine behave in ways that would be called intelligent if a human were so behaving" (McCarthy, Minsky, Rochester & Shannon, 1955). Many AI researchers in that period predicted that a machine as intelligent as a human being would exist in no more than a generation. However, despite this well-funded global effort over several decades, computer scientists found it incredibly difficult to create intelligence in machines. Failing to meet public expectations, computer scientists dealt with an acute shortage of funding for AI research from the mid-1970s to the mid-1990s, known as the "AI Winters." Investment and interest in AI boomed in the first decades of the 21st century, when machine learning was successfully applied to many problems in academia and industry due to new methods, the application of powerful computer hardware, and the collection of immense data sets. AI study as an up-to-date science study is developing at a fast pace now (Popenici & Kerr, 2017). In recent studies, researchers like Kaplan and Haenlein (2019) redefined AI as "a system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation" (p. 17). As science and technology advances, AI has led human history to the "Fourth Industrial Revolution" (K. Schwab, 2016), a new age in which the way of life and work of human beings has been profoundly changed. The applications for artificial intelligence appear to be endless. AI is being used in the healthcare industry for surgical procedures and dosing drugs, transportation industry such as self-driving cars, business such as shopping recommendations, and relaxation such as playing chess and composing music. At the same time, AI has its limitations and has raised many issues such as safety and privacy. Thus, AI literacy becomes a necessary part of human knowledge in a new era. The development of AI technology raises a fundamental question on how education could prepare people, especially K-12, to live and work harmoniously with this new technology.

1.2 « Research Field: AI and Education »

AI may be incorporated in education in two general contexts: 1. AI as a tool in education. 2. Education on AI as a topic of study which can be further divided into (a) higher education on AI as a specialized, technological topic of study for AI experts, and (b) K-12 education on AI knowledge of what AI is and its impact on society. My research will focus on education on AI for K-12 in the field of curriculum study in which there is an urgent need to demystify AI and familiarize students, especially K-12, with the nature of AI and its current and future impact(s) on both daily life and work. However, the availability of AI curricula for K-12 is currently deficient at all levels and only a few schools and organizations worldwide have provided courses or training on the subject (Welk, 2020). Thus, examining the existing AI curricula and analyzing their basic elements and pedagogical approaches, evaluating their merits and bias becomes an urgent need for educational studies in the current era.

1.3 « Research Questions »

The research on the application of AI technology to education has been the subject of research for about 30 years (Olaf, Marín, Bond & Gouverneur, 2019). It has become a major part of AI education research in recent years. While there are relatively fewer curriculum studies on AI courses and training programs, the development of an AI curriculum itself is on a primary stage. Currently, a wide gap remains in teaching resources such as curricula for teaching AI for K-12. The lack of experimental data or tested Curricula for educators and researchers to consult might be the reason. Hence, my research addresses the following questions:

1. What are the basic elements of the existing AI curricula for K-12?

2. How do these AI curricula for K-12 converge and diverge in their features of pedagogical approaches?

As a complete and coherent curriculum requires the articulation of each of the four curriculum "commonplaces" suggested by Joseph Schwab (1969), that of the teacher, the student, the subject matter, and the social milieu, the first research question can be further divided into four sub-questions:

1. What are the subject matters included in the existing AI curricula for K-12?
2. What are the roles of the teachers of the existing AI curricula for K-12?
3. What are the roles of the students of the existing AI curricula for K-12?
4. What are the milieux of the existing AI curricula for K-12?

According to Murphy (2009), pedagogy is the term that describes the relationships and "interactions between teachers, students and the learning environment and the learning tasks" (p. 35). Based on this definition of pedagogy, the second research question involves a holistic comparison of the basic elements of the selected AI curricula for K-12 on the interactions of students and teachers, and the learning environments in which the teaching and learning occur, and their relationship with the learning tasks.

1.4 « The Structure of the Study »

In chapter one, I provide a brief introduction to my study and depict my concerns about what basic elements and pedagogical approaches are included in the selected AI curricula for K-12. Chapter two reviews the relevant bodies of research literature on what is known about AI education. Chapter three introduces Piaget's constructivism, Vygotsky's social constructivism, and Papert's constructionism as the theoretical framework of this study. Chapter four describes the methodological underpinnings and research methods of the study. Chapter five presents the findings of data analysis. In chapter six, I discuss the findings using the lens of (socio) constructivist and constructionist theories. The

Conclusion summarizes the thesis and suggest some implications for educators, researchers, and policymakers to consider in the future.

Chapter 2

2 « Literature Review »

Before answering these research questions, it is important to review the relevant literature. Firstly, it is helpful to review the literature on the context of AI education, as this will be an issue to be discussed in terms of the social and political influences on the divergence of AI curricula once the content analysis has been done. Additionally, the literature on the importance of AI education supports the rationale of my study. Literature documenting higher education on expert AI knowledge is relatively extensive and will be briefly reviewed to provide the overall categories within which findings of content analysis on AI curricula for K-12 could be inserted. Literature addressing my research questions was limited, and this became evident when reviewing literature in terms of AI curricula for K-12. Finally, the literature on the reform of AI education will provide the background of evaluating the selected AI curricula. Thus, in the literature review section, four groups of literature will be discussed: the context of AI education, the important role of AI education, AI curriculum study, and reform on AI education.

2.1 « The Context of AI Education »

The national AI strategies and educational policies, and journal articles and AI strategy reports form the literature on the context of AI education.

2.1.1 National AI Strategies and Educational Policies

The national AI strategies and educational policies of different countries can serve as important literature on the context of the development of AI education. The important role of AI in international competition has drawn great attention from many countries. Early in 2016, the United States, as the leading country in the field of AI technology, promulgated three important documents on developing AI: *Preparing for the Future of Artificial Intelligence* (United States, 2016a), *The National Artificial Intelligence Research and Development Strategic Plan* (United States, 2016b) and *Artificial Intelligence, Automation, and the Economy* (United States, 2016c). In March 2017, Canada was the first country in the world to announce a national AI strategy: *the CIFAR*

Pan-Canadian Artificial Intelligence Strategy (Canadian Institute for Advanced Research, 2017). Following Canada's lead, more than twenty countries have issued AI national strategies (see Figure 1). Many of these national strategies mention that AI has become a driving force for future educational reform. AI education policies form an important part of government initiatives that support national AI strategic planning. In Asia, the Chinese government, for example, has launched a series of development plans for AI education. Following the *2017 New Generation of Artificial Intelligence Development Plan* (Chinse State Council, 2017), which clearly stated the plan to set up courses related to Artificial Intelligence in primary and secondary schools, "Artificial Intelligence" was listed as a selective compulsory course in the *New Curriculum Standard of Ordinary Senior High Schools* issued in 2017 (Insights, G. E. T. C., 2019). In June 2018, the Indian government defined a national policy on AI in a working paper titled *National Strategy for Artificial Intelligence #AIforAll* which identifies five focus areas where AI development could enable both growth and greater inclusion: healthcare, agriculture, education, urban-/smart-city infrastructure, and transportation and mobility (NITI Aayog, 2018). In the same year, the European Union formulated the *Communication on Artificial Intelligence for Europe* (European Commission, 2018), and the British government formulated the "Industrial Strategy Artificial Intelligence Sector Deal" (United Kingdom, 2018). The Australian federal government has "earmarked $29.9 million over four years to enhance Australia's efforts in artificial intelligence and machine learning in the country's 2018-19 budget" (*AI policy-Australia*, 2018). Figure 1 by Dutton (2018) demonstrates the release of national AI strategies in chronological order:

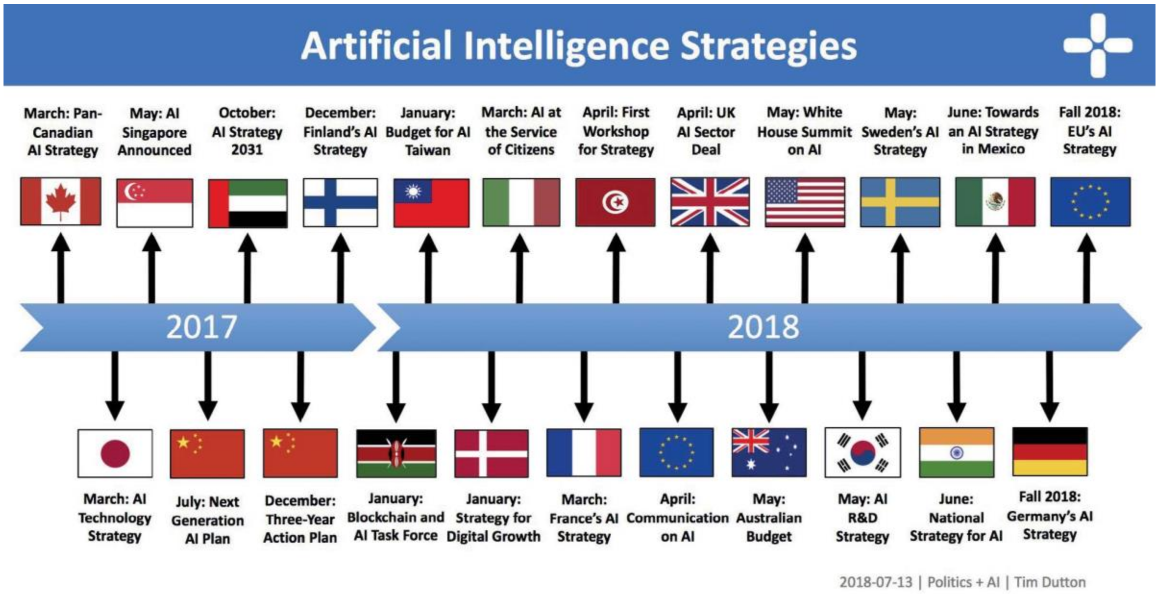

Figure 1: National AI Strategies

As shown in Figure 1, in the years of 2017 to 2018, 21 countries formulated their national AI strategies. The national AI strategies provide an important context for the direction of AI and its impact on everyday life, industry, education, and research.

2.1.2 Journal Articles and AI Strategy Reports

Besides national AI strategies, journal articles, and AI strategy reports published by private or government-sponsored organizations serve as additional literature to interpret these strategies and provide a clear explanation of the context of AI education. Many governments are slowly beginning to acknowledge the fact that gaining a broader understanding and the necessary skills related to AI can be considered an essential component for young people to succeed. In the United Kingdom, a report was published by a Select Committee on Artificial Intelligence appointed by the House of Lords in 2018: *AI in the UK: ready, willing and able?* (House of Lords of the UK Parliament, 2018). It suggested that "regardless of the pace of AI development, it is inevitable that AI will impact future generations" (Wong, Ma, Dillenbourg & Huan, 2020, p. 22). Yang (2019) analyzes key government policies relevant to the implementation of AI in Chinese education, arguing that AI education is at its early stage in elementary education; more prevalent in higher education and civic education in China. According to Yang (2019), China is searching for the point where "top-down system design" meets "bottom-up applications" to plan courses on AI (p. 352). Miller and Stirling's report (2019) *Government Artificial Intelligence Readiness Index 2019*, commissioned by Canada's International Development Research Centre (IDRC) as part of its AI for Development (AI4D) initiative, provides comments on the seven major regions of the world. The report mentions the interests of different groups in the national strategies of leading countries in each region. For example, when talking about the adoption and utilization of AI in the current context, the report says, "China's advantage lies in its abundance of data (and loose privacy laws)" (Miller & Stirling, 2019, p. 12). Unlike many other countries that are forming policies to "boost investment and leverage AI for national competitiveness" (Miller & Stirling, 2019, p. 22), the Pan-Canadian Artificial Intelligence Strategy focuses almost exclusively on establishing Canada as the AI research leader by attracting and cultivating top AI talent. Also, Heumann and Zahn (2018), in their report *Benchmarking National AI Strategies*, focused their study on the goals of National AI strategies. However, they add the "success indicators" (p. 2) of the selected six prominent national AI strategies for examination, regarding the extent to which they define clear goals and delivery indicators. Similarly, Paunov, Satorra, and Ravelli (2019) focused on the application of digital breakthrough and AI-driven innovation in their review of national policy initiatives in support of digital and AI-driven innovation. The World Economic Forum report (2019) covers the concept of stakeholders when discussing the development and impact of AI. As the report states, "the technological force that will have a multisector impact will need to be steered and guided in the country's desired strategic direction; this should be done through assigning specific responsibilities to all of the stakeholders – ministries, legislature, enterprises, academia and ecosystem players" (2019, p.13).

These documents manifest the motivation and determination of the governments to develop artificial intelligence and education, which have triggered an interest in research on AI education in the academic field.

2.2 « Importance of AI Education »

In the academic field, many researchers have demonstrated the importance of AI education. Woolf, Lane, Chaudhri, and Kolodner (2013) argued that AI will be a "game changer in education" and AI and education can be regarded as "two sides of the same coin": education helps students accumulate knowledge and AI technique facilities their learning on the "mechanisms underlying thought, knowledge, and intelligent behavior" (p. 67). Han, Hu, Xiong, Liu, Gong, Niu, Shi, and Wang (2018) stated that AI education in primary and secondary schools has become an essential part of the implementation of national AI strategy in China. According to Chrisinger (2019), "a curriculum and delivery model that provides the workers of the future the multidisciplinary skills the market will require" is urgently needed, as "incorporating a consciousness of AI and its challenges" into lifespan and career will lead to "the human and technological benefits of this next frontier" (p. 4). According to Touretzky, Gardner-McCune, Breazeal, Martin, and Seehorn (2019a), "We need to engage students throughout their education starting as early as kindergarten through high school (K-12) and encourage early consideration of AI-related careers" (p. 88).

2.3 « AI Curriculum Studies »

As mentioned in Chapter 1, education on AI has two parts: AI education for Higher Education and AI Curricula for K-12. This section will discuss AI curriculum studies on higher education and AI curriculum studies on K-12.

2.3.1 AI Curriculum Studies on Higher Education

For AI curriculum studies, the majority of research on AI education focuses on the tertiary education level with the aim of teaching AI concepts and mechanisms to university undergraduate and graduate students to cultivate future AI experts. Examples are Torrey's (2012) research on teaching strategies for Algorithms and AI courses to undergraduate students; McGovern, Tidwell, and Rushing's (2011) research on teaching introductory artificial intelligence through Java-based games in a mixed undergraduate graduate AI course; Keating and Nourbakhsh's (2018) research on Carnegie's human-machine interactions course on first-year undergraduate students, etc. In undergraduate education, fun and inspiring ways are applied to engage students in various aspects of AI learning, such as modeling and simulation, robotics, machine learning, and game playing (Dodds, Hirsh, & Wagstaff, 2008). At the University of California, an introductory AI course was designed to teach AI concepts using the classic game Pac-Man which takes a project-centered approach focusing on closely related topics (DeNero & Klein, 2019). The University of Southern California has also incorporated a project-based approach using games to teach concepts of computer science and standard AI in their Bachelor's and Master's degree programs in Computer Science (Wong, Zink, & Koenig, 2010). At the University of Oklahoma, introductory AI courses are being taught applying java-based games and robots to visualize abstract AI concepts. The method of creating a fun-based learning context through games and robots ensures high level of student interest and engagement throughout the process of the course (McGovern, Tidwell & Rushing, 2011). Research on AI education at tertiary level provides the experience that AI education for K-12 could borrow. Also, the study on what and how AI is taught in tertiary education will trigger the thought on how AI education for K-12 could prepare students for their future AI-related education and career.

2.3.2 AI Curriculum Studies on K-12

Research on the existing AI curricula for K-12 is relatively scarce, as AI education for K-12 itself is "still in its infancy with major concerns that require solutions—insufficient funding, resources, as well as how CS educators will be trained to teach AI competently" (Wong, Ma, Dillenbourg & Huan, 2020, p. 23). Not many curricula are available on the current stage. However, there are some attempts. The early research of Fok and Ong (1996), Heinze, Haase, and Higgins (2010), and Tsukamoto, Takemura, Nagumo, Ikeda, Monden, and Matsumoto (2015) focused on teaching specific AI subjects at the school level. Commenting on Fok and Ong (1996) and Heinze, Haase and Higgins's (2010) work as only dealing with some selected aspects of AI, for example, history, Turing Test, chatbots, neural networks, etc., Burgsteiner, Kandlhofer and Steinbauer (2016) introduced the structure, content and teaching methods of their pilot project in Australia. They developed an AI-course (called "iRobot") teaching high school students "major topics of AI/computer science (automatons, agent systems, data structures, search algorithms, graphs, problem solving, planning, machine learning)" (p. 4126). Their course was composed of seven weekly teaching units, covering both theoretical and hands-on components.

More recently, Han et al. (2018) introduced a Chinese AI education program in primary and secondary schools in Qingdao City. In their research, Han et al. (2018) proposed an "AI+" curriculum which mainly "adopts the method of + knowledge acquisition, + technical training, + immersion experience, + project learning, and + social practice to design and implement" (p. 4137). Similarly, the online *Wall Street Journal* introduced Blakeley H. Payne's research done at the MIT Media Lab (Ma, 2019). Payne, a graduate research assistant at MIT, has designed an AI curriculum to teach school children about the ethics of AI in which each lesson typically includes "a short lecture and demonstration, followed by a group activity and open-ended discussion" (Ma, 2019).

Besides Payne, the MIT Media Lab, which was established by Papert in 1985, has a group of researchers focusing on AI education for K-12. Ali, Williams, Payne, Park, and Breazeal (2019) introduced their research on developing K-8th grade curricula that emphasize constructionist learning in order to educate a future citizenry who "understand AI, learn about ethics, think creatively" and can thrive in the development of the future of AI (p. 1). Williams, Park, and Breazeal (2019) believed that early AI education can empower children to understand AI devices. In their research, they developed PopBots, a novel early childhood AI platform, for preschool children to train and interact with social robots for the purpose of introducing them to three AI concepts: knowledge-based systems, supervised machine learning, and generative AI. Williams, Park, Oh, and Breazeal (2019) designed the PopBots Platform and a Curriculum consisting of a social robot toolkit, three hands-on AI activities, and associated assessments for young children to explore AI concepts such as machine learning, reasoning, and generative algorithms. They argued that the use of the PopBots platform as a programmable artifact and learning companion is effective in helping young children learn AI concepts.

For in-school AI education, the David E. Williams Middle School of the US has employed a three-week pilot AI curriculum using the AI-in-a-Box kit provided by

ReadyAI (Wong, Ma, Dillenbourg & Huan, 2020). According to Wong et al. (2020), the AI curriculum "exposes students to potential careers in robotics and automation, and gives them the opportunity to examine technologies that are used every day" and "questions regarding the ethics and potential dangers of the proliferation of AI" (p.23). Alpay Sabuncuoglu (2020) introduced their 36-week open-source AI curriculum for middle school education in Norway which "structures the past research and resources in a complete one-year course" and suggests "exploring digital content and with the physical tasks promise an interesting design space" (p. 101). The dates of these research and educational practices indicate that education on AI for K-12 is on a primary stage. An integrated study on the existing AI curricula is needed.

2.4 « Reform on AI Education »

This section will discuss the literature introducing current research organizations and their initiatives on education on AI for K-12, a frequent topic for discussion on whether to set up new AI courses or to incorporate AI knowledge into some existing school curricula, and the expectations on the future development of AI education.

2.4.1 Current Initiatives on K-12 AI Education Reform

Touretzky, Gardner-McCune, Martin, and Seehorn's (2019a) paper introduced the current situation of research groups and their initiatives on AI education for K-12. According to Touretzky et al. (2019a), a joint initiative - the AI4K12 Initiative was launched in May 2018 by the Association for the Advancement of Artificial Intelligence and the Computer Science Teachers Association with the purpose of developing guidelines for teaching AI on K–12 level. The AI4K12 Working Group, composed of AI researchers, AI curriculum developers, and practicing teachers, published their five big ideas in AI teaching as the framework for the guidelines in teaching AI to K-12 (Touretzky et al., 2019a). Each of the five big ideas is "unpacked into a set of concepts and subconcepts that are further expanded for each grade band (K–2, 3–5, 6–8, and 9–12) and then summarized in a progression chart" (p. 89). Other organizations that have begun to study the issue and develop AI learning frameworks for K-12 students include AI4All (http://ai-4-all.org/), MIT Media Lab, and the International Society for Technology in Education

(ISTE). These initiatives are “laying the groundwork for AI education in K12” (Touretzky, Gardner-McCune, Martin & Seehorn, 2019b, p. 9796).

Besides the US, parallel efforts to develop K–12 AI Education capabilities are seen in numerous other countries. Australia has undertaken similar steps in its endeavor to teach AI at the kindergarten and primary levels (Heinze, Haase & Higgins, 2010). Under the Scientists-in-Schools program, K-6 teachers collaborate with AI researchers to deliver AI concepts using appropriate methods to young individuals. Other countries such as “China, Finland, the United Kingdom, Canada, Turkey, Portugal, South Korea and Argentina” have seen a growth of K-12 AI education programs and curricula (Touretzky et al., 2019a, p. 89).

Ethical aspects have drawn more and more attention from academia. Some institutions have recently been established, such as the Institute for Ethical AI in Education in the UK, which endeavor to produce a framework for ethical governance for AI in education, and the Analysis & Policy Observatory which has published a discussion paper in April 2019 on developing an AI ethics framework for Australia (Olaf, Marín, Bond & Gouverneur, 2019).

2.4.2 Setting up AI Courses VS. Incorporating AI Knowledge into Existing School Curricula

In the field of general AI education for K-12, the discussion on the necessity and feasibility to establish new AI courses in K-12 AI education has attracted some researchers. Researchers such as Han et al. (2018) support the idea of establishing new AI courses in schools supporting the Chinese educational policy on establishing AI courses in primary and secondary education. However, more educators and researchers hold the view that AI knowledge can be incorporated into other existing STEM courses like math and computer science. Gadanidis (2017) made an analysis of the intersection of artificial intelligence, computational thinking, and mathematics education for schoolers, setting a conceptual foundation for future research in this field. Thus, AI syllabus may be regarded as part of a whole of curricula approach to studies that integrate other subjects such as science, art, literacy, numeracy. Bojic and Arratia (2015) introduced a training program that teaches AI knowledge to school students (K-12) in STEM fields. Similarly, Sung and Black (2017) did an experimental study on introducing computational thinking to the existing math and computer programming class in elementary schools. Heinze, Haase and Higgins (2010) introduced the Scientists-in-Schools program in Australia which has launched a multi-year pilot AI course to K-6 students and have already identified key insights in what and how AI knowledge should be taught at this level. Heinze et al. (2010) provided details of and reflections on an AI program at the K-6 level in Australia. They argue that a "cross-curricula approach" to the teaching of AI by "incorporating science in general and AI in particular into other parts of the curricula" would benefit students (p. 1892). Wong, Ma, and Huen (2019) introduced how the Education Bureau in Hong Kong integrates AI into the K-12 curriculum. They studied an initial AI program that has been introduced to several international and local secondary schools in Hong Kong as part of the extra-curricular activity. In their study, they also pointed out the ways that AI education should be implemented such as to identify "foundational knowledge", to identify teaching "tools" and to provide "appropriate training" to educators (p. 27).

2.4.3 Future of AI Education

Many researchers in the above section also talked about the future of AI education besides suggesting the best way of teaching AI knowledge. However, some articles are focusing on foreseeing the future of AI education. Woolf et al. (2013) focused their study on what AI can do to achieve "long-term educational goals" (p. 66). Interestingly, in the same year, both Roll and Wylie (2016) and Timms (2016) foresaw the scenario of AI education in the next 25 years. However, the two papers focused on different aspects. Roll and Wylie focused more on the "evolutionary process" and "revolutionary process" of prospective achievements in AI education and describe the general pictures of it (p. 582), whereas Timms laid more emphasis on Cobots and its interaction with humans in education.

To ensure that AI instruction is accessible and developmentally appropriate for all students, curriculum and tool development efforts need to be iterative, collaborative processes that involve active participation among all stakeholders, including developers, teachers, and the students themselves (Touretzky et al., 2019a, p. 89).

Chapter 3

3 « Theoretical Framework »

Constructivism, social constructivism and constructionism theories serve as the theoretical framework of my study for two reasons. First, according to Terwel (1999), a single theory, in principle, “cannot provide a solid foundation for educational practice” (p. 196). To provide an adequate underpinning of ideas to educational practice, educators need to create a “polyfocal conspectus, which unites elements from multiple theories, along with heuristics drawn from experience, into a coherent basis for action” (Terwel, 1999, p. 196). With different foci, Piaget’s constructivism, Vygotsky’s social constructivism and Papert’s constructionism theories overlap, complement and integrate, which can provide multiple yet focused theoretical lens to the findings of the data analysis of my study. Piaget’s constructivism and Vygotsky’s social constructivism will serve for supplementary and comparative purposes. Second, both constructivism and constructionism have their connection to AI education. Piaget had a considerable effect in the field of computer science and artificial intelligence (Drescher & Gary, 1991). Papert (1980) used Piaget's work when he developed the Logo programming language. Piaget’s theories were used as the basis for the Dynabook programming system concept (Drescher & Gary, 1991). “Little AI” is a pedagogical game developed to present the founding concepts of constructivist learning and developmental Artificial Intelligence (Georgeon, 2017). More importantly, Papert (2004) was “one of the pioneers of artificial intelligence and of the Constructionist movement in education” (p. 9). According to Williams, Park, Oh, and Breazeal (2019), “the first idea to teach children about AI came from Cynthia Solomon and Seymour Papert in 1971” (p. 2). They wanted children to explore AI through LOGO programming and the Turtle robot (Papert & Solomon, 1971). In the early 1960s, Papert founded the MIT Artificial Intelligence Lab. Papert’s most influential work, *Mindstorms: Children Computers and Powerful Ideas* (1980), has a whole chapter (Chapter 7 Logo’s Roots: Pieget and AI) on artificial intelligence (pp. 156-76). Papert proposed to teach AI to children so that they can “think more concretely about mental processes” (1980, p. 158). Together with *Mindstorms: Children Computers and Powerful Ideas* (1980), *The Children’s Machine: Rethinking School in the Age of the*

Computer (1993), and *The Connected Family: Bridging the Digital Generation Gap* (1996) can all shed light on AI education from different perspectives, namely, educators, learners and parents (Stager, 2016), and more generally the role of computational environments (such as Papert's Logo) in education. Papert was a huge proponent of bringing new technology to learnings. To Papert, technology is the means as well as objective of education, as learning occurs through creative involvement in the social context in which technology is an important part.

Thus, constructivism, social constructivism and constructionism are combined to form the theoretical framework of the study on the selected AI curricula with constructionism as the core theory. This theoretical framework can be proper in that it provides the effective lens for data interpretations in Chapter 6 from multiple perspectives.

3.1 « Development of Constructivism, Social Constructivism and Constructionism »

In this section, the development of Piaget's constructivism, Vygotsky's social constructivism, and Papert's constructionism and their connections will be introduced.

3.1.1 Piaget's Constructivism

Constructivism can be traced back to educational psychology in the work of Jean Piaget (1896-1980), a Swiss psychologist (Steffe, Gale, 2012). Constructivism in education is "an approach to learning which holds that people actively construct or make their knowledge and that reality is determined by the experiences of the learner" (Elliott, Kratochwill, Littlefield & Travers, 2000, p. 256). The central idea of constructivism is that human knowledge is constructed, and learners build new knowledge upon their previous learning. Piaget (1970) inserted that knowledge is not merely transmitted verbally from the teacher to the students but is constructed and reconstructed by the students. Piaget also argued that a child must act on objects to know and construct knowledge of the world, and it is this action which provides knowledge of those objects (Sigel & Cocking, 1977). Different from earlier educational philosophies which saw play and exploration as aimless and of little importance in their education, Piaget (1971) saw play as an important and necessary part of the children's cognitive development. To Piaget, learning is a process of actively exploring new information and constructing meaning from this information by connecting it to previous knowledge and experience (Alesandrini & Larson, 2002).

3.1.2 Vygotsky's Social Constructivism

Lev Vygotsky (1896-1934) was a Russian psychologist, the founder of an original holistic theory of human cultural and biosocial development. Similar to Piaget, Vygotsky held that young children are actively involved in their own learning and the discovery and development of new understandings of the world. While Piaget emphasized self-initiated discovery and focused on human development in relation to what is occurring with an individual as distinct from development influenced by other people, Vygotsky's theory of social constructivism emphasized the fundamental role of social interaction in the development of cognition. Different from Piaget's idea that children's mental development must necessarily precede their learning, Vygotsky argued that "learning is a necessary and universal aspect of the process of developing culturally organized, specifically human psychological function" (1978, p. 90). Thus, all teaching and learning is a matter of sharing and negotiating socially constituted knowledge. Similar to Dewey's (1938) idea that learning is a social activity (something people do together and interact with each other), social constructivists put more emphasis on the social background and culture of the learner throughout the whole learning process, as it helps to shape the knowledge in the learning process (Wertsch, 1997).

3.1.3 Papert's Constructionism

Working with Piaget in Geneva in the late 1950's and early 1960's, Seymour Papert (1928-2016) based his constructionist learning theory on Piaget's work on cognitive development. Papert's constructionism has overlaps with constructivism and social constructivism as learning theories. Papert identified the connection of his theory with and its development from Piaget's constructivism in his own words:

> Constructionism—the N word as opposed to the V word— shares constructivism's view of learning as "building knowledge structures" through progressive internalization of actions… It then adds the idea that this happens especially

> felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sandcastle on the beach or a theory of the universe (Papert & Harel, 1991, p. 1).

Seymour Papert (1987) defined constructionism in *Constructionism: A New Opportunity for Elementary Science Education*, a proposal to the National Science Foundation , as follows:

> The word constructionism is a mnemonic for two aspects of the theory of science education underlying this project. From constructivist theories of psychology, we take a view of learning as a reconstruction rather than as a transmission of knowledge. Then we extend the idea of manipulative materials to the idea that learning is most effective when part of an activity the learner experiences as constructing a meaningful product. (p. 2)

Constructionism focuses on learning to learn (Ackermann, 2001) and believes that individuals are builders of their own knowledge (Papert, 1980). The main credo of Papert's constructionist theory of education is that people effectively build knowledge when actively engaged in constructing things in a concrete learning/making context (Harel & Papert, 1991). Constructionism suggests that by enabling learners to build their "creative artifacts that require complex content to function," the learners will be given opportunities to "learn that complex content in connected, meaningful ways" (Berland, Baker & Blikstein, 2014, p. 206).

3.2 « Doctrines of Constructivism, Social Constructivism and Constructionism »

In the following part, the doctrines of Jean Piaget's constructivism, Vygotsky's social constructivism and Papert's constructionism theories will be summarized in terms of what to learn, what roles students and teachers play, how to learn, and what environment/tools are involved in learning with an emphasis on constructionism.

3.2.1 Structure of Knowledge.

Piaget (1970) believed that intelligence is a single capacity that all individuals develop in the same way. Concerning knowledge structure, Piaget (1970) argued that “assimilation” and “accommodation” are two key components that create the construction of an individual’s new knowledge. Assimilating causes an individual to incorporate new experiences into the old experience by developing new outlooks, rethinking what were once misunderstandings, and evaluating what is important, ultimately altering their perceptions. Moreover, accommodation, reframes the world and new experiences into the existing mental capacity. Piaget also believed that people become capable of conducting their own learning when they are psychologically qualified at certain age with certain levels of understanding.

The structure of knowledge is talked about by Vygotsky, too. Vygotsky’s “zone of proximal development” is defined 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” (Vygotsky, 1978, p. 86). It differs from the fixed biological nature of Piaget’s stages of development in that an individual in a social constructivist context has the possibility to reach something beyond their age limit defined by Piaget. For the social constructivist, knowledge should be discovered as an integrated whole instead of being divided into different school subjects or compartments. Through problem solving, students set up a non-linear process of collective knowledge-construction to present new contents with their classmates (Vygotsky, 1978).

Papert agrees with Vygotsky on this point but emphasizes on the effect of tangible artifacts as “tools to think with” (Papert, 1980, p. 76). Papert (1980) stated that “the importance of studying the structure of knowledge is not just to better understand the knowledge itself, but to understand the person” (p. 164). According to Papert and Harel (1991), people construct their own knowledge when creating tangible artifacts to practice what they have learned based on their previous knowledge and their individual learning experience. Thus, knowledge is structured by building new knowledge upon previous knowledge through interactions with the world. To constructionist learners, arts and design are integrated with the subjects being taught and knowledge is shaped when learners design and construct products (Papert & Harel, 1991). On artificial intelligence, Papert mentioned that researchers apply “computational models” to obtain insight into and reflect on “human psychology as a source of ideas about how to make mechanisms emulate human intelligence” (1980, p. 164).

3.2.2 Roles of Teacher and Students.

Students are the center of constructivist, social constructivist and constructionist theories. Constructivists see learning as a process of actively exploring new information and constructing meaning from the new information by linking it to previous knowledge and experience. Throughout the learning experience, meaning is constructed and reconstructed based on the previous experiences of the learner (Alesandrini & Larson, 2002). The teacher’s role is not to lecture or provide structured activities that guide students. Instead, “teachers in a constructivist classroom are called to create a classroom environment as facilitators who coach learners as they blaze their own paths toward personally meaningful goals” (Alesandrini & Larson, 2002, p.118).

While Piaget held that a child’s cognitive development stems mainly from independent explorations of the world in which children construct their own knowledge, Vygotsky (1978), inserted that cognitive development develops from social interactions with a skillful tutor in guided learning (McLeod, 2018). The tutor (often the parent or teacher) may provide for the child model behaviors and/or verbal instructions referred to by Vygotsky as cooperative or collaborative dialogue as children and their partners co-construct knowledge. The child seeks to understand the tutor’s actions or instructions then internalizes the information, using it to guide or regulate their own performance (McLeod, 2018). Vygotsky (1978) also advocated collaborative learning in which group members of different levels of ability can work together so that more advanced members can help less advanced peers operate within their zone of proximal development.

Like (socio) constructivism, constructionism also proposes student-centered, discovery learning where student agency is emphasized to acquire more knowledge (Ackermann, 2001). Instead of adopting the traditional instructor role, the constructionist teacher assumes a mediation role in teaching, becoming a facilitator by coaching students and affording them opportunities to develop and attain their own goals (Ackermann, 2001).

Delivering knowledge to students is replaced by helping them to comprehend—and assist their peers to comprehend—problems in a hands-on way (Papert & Harel, 1991). So, similar to social constructivism, constructionism advocated collaborative learning. For the student's role, constructionism theory advocates that each student should control their own learning process to acquire something useful and valuable for their knowledge. Student agency is emphasized in which students should be self-directed in their learning process and should reach their own conclusions through creative real-world experimentation and the making of social objects (physical or digital objects). Thus, students are the center of the constructionist teaching/learning activities.

3.2.3 Learning by Constructing.

Learning by constructing is a fundamental idea of all the three theories. This idea can be traced back as far as the early 1900s when John Dewey (1916) proposed learning by doing. Constructivism (Piaget, 1970) stated that learners construct their individual knowledge through active construction of meaning. Piaget's (1971) theory suggested that children utilize skills and abilities they were born with to experience the world and gain knowledge through their senses and motor movements. Piaget (1971) maintained that children progress through a series of four different stages of cognitive development that encompass numerous aspects of mental development including reasoning, language, morals, and memory.

Piaget's theory provides a solid framework for understanding children's ways of doing and thinking at different levels of their development. Like Piaget who focused on motor reflexes and sensory abilities of infants, Vygotsky stated that infants are born with the basic materials/abilities for intellectual development (McLeod, 2018). However, Vygotsky stressed that cognitive development is a result of social interactions from guided learning within the zone of proximal development as children and their peer's co-construct knowledge (McLeod, 2018).

Constructionism goes further by emphasizing that learning occurs most effectively when people are actively making tangible objects in the real world (Ackermann, 2001). Papert proposed that individuals learn best when they are constructing an artifact, which can be physical, semi-physical or digital, and can be shared with other people and reflected upon, such as Logo programming (Harel & Papert, 1991). This expands Vygotsky's social environment to include non-human participants, which together with humans, form a "cognitive ecology" (Levy,1997) that helps reorganize collective knowledge and understanding (Borba & Villareal, 2005).

3.2.4 Learning Environment and Tools.

Constructivism encourages students to discover, discuss and interpret knowledge in learning environments which can help students construct and implement their own theories and motivate reflection of gained knowledge and skills (Jonassen, 1999). Constructivist learning environment emphasizes a meaningful learning context rather than abstract instruction out of context.

Social constructivism stresses the role of cultural artifacts — tools, language, people —as a resource of people's cognitive potential (Ackermann, 2001). Vygotsky (1978) noticed the importance of sociocultural learning which emphasizes the learner's social interaction with more knowledgeable members of the society (adults, more capable peers) to acquire social meaning and utilization of important symbol systems. Vygotsky (1934/1962) argued that learning could not be separated from social context and emphasized the role of language and culture as learning environment. Language and culture play essential roles both in human intellectual development and in how humans perceive the world, as Vygotsky (1978) stated:

> Every function in the child's cultural development appears twice: first, on the social level and, later on, 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)

Language and the conceptual schemes are essentially social phenomena. Thus, language and culture are the frameworks through which humans experience, communicate, and understand reality.

Similarly, constructionist theory emphasizes the importance of tools, media, and context in education (Ackermann, 2001). One of the classic quotations on the use of the computer as a tool from Papert's landmark book, *Mindstorms: Children, Computers, and Powerful Ideas* (1980), is:

> For me, the phrase "computer as pencil" evokes the kind of uses I imagine children of the future making of computers. Pencils are used for scribbling as well as writing, doodling as well as drawing, for illicit notes as well as for official assignments. (Papert, p. 210)

In *Mindstorms*, Papert (1980) advocated "the construction of educationally powerful computational environments that will provide alternatives to traditional classrooms and traditional instruction" (p. 182). Papert (1980) mentioned his childhood gears in the preface of *Mindstorms* as models to carry abstract ideas. His major work focuses on how technology can provide children the coding "gears" to take part in the understanding of the world. Papert was a co-inventor of the Logo programming language, which were inspirations to the creation of Scratch, a block-based programming environment. Papert also put robot turtles controlled by Logo programming language into visionary research which has bridged the world of Lego construction (tangible tools) with the world of Logo programming (abstract coding). Papert saw these tools as objects-to-think-with and may be seen as similar to socio-constructivism (Vygotsky, 1978), cognitive ecology (Levy, 1997) and humans-with-media (Borba & Villareal, 2005).

3.2.5 Summary of Theories

Table 1 provides a summary of the doctrines of the three theories involved which will serve as lens of the data analysis and interpretation.

Table 1: Summary of Theoretical Framework

	Constructivism	Social Constructivism	Constructionism
Doctrines in common	·Student construct knowledge through meaningful experience		

Different foci	·It emphasizes self-initiated discovery and cognitive development of children. ·Learners build new knowledge upon their previous learning.	·It emphasizes collaborative nature of learning. ·It stresses cultural and social learning context.	·Students learn best by making tangible objects, whether physical or digital. ·It stresses technology fluency and integration in learning.

Chapter 4

4 « Methodology »

This chapter discusses the research methods. I employ qualitative document analysis in this research. I initially state the rationale for taking qualitative approach and document analysis for this study. Then, I clarify the procedures of data analysis and the analytical frameworks that will be used in Chapters 5 and Chapter 6.

4.1 « Qualitative Approach »

Within the field of Curriculum Studies, I will take qualitative approach as my methodology. Babbie (2014) defined qualitative research as a "scientific method of "observation" to gather "non-numerical data" (p. 303-04). Berg (2012) stated that qualitative research "refers to the meanings, concepts, definitions, characteristics, metaphors, symbols, and description of things" and not to their "counts or measures" (p. 3). In contrast to its quantitative counterpart, qualitative research focuses on the interpretation of holistic meanings of the research subject rather than the measurement of a part of it. Qualitative methods are appropriate for this study because the essential objective of the study is to provide exploratory and descriptive information that is context specific (Marhsall & Rossman, 1995). This study is of an interpretive nature, as the objective is to identify and analyze the basic elements and pedagogical approaches of the selected AI curricula for K-12.

4.2 « Research Paradigm »

My qualitative approach shares some common ground with my philosophical stance as a researcher. In educational research, I take the social constructivist paradigm that knowledge is collectively constructed in a learning context, and the researcher is actively involved in the research process. The researcher's beliefs and experiences will affect the result of the research because their interpretation and construction of meanings are based on their beliefs and experiences (Vygotsky, 1978). Two major sources contribute to my constructivist interpretive paradigm as a researcher. First, constant reflections on my 23-year language teaching career and research lead me to this paradigm and its ontological and epistemological assumptions. I believe instead of memorizing each sentence learned, language learners generate new sentences based on the knowledge they have already known, and this learning process is affected by its context. In addition, the courses on research methodology and related readings in my MA program contribute to the development of such philosophical assumptions in research, which in turn, help me to develop my research methodology in my educational research context. This paradigm, combined with my research intent, determines the methodology of my research on AI curricula for K-12.

4.3 « Document Analysis »

The primary research method for this study is qualitative document analysis. Document analysis is a form of qualitative research in which documents are analyzed and interpreted to trace meaning around a topic being assessed (Bowen, 2009). Document analysis involves a systematic research "procedure for reviewing or evaluating documents" (Bowen, 2009, p. 28). The procedure involves "finding, selecting, appraising (making sense of), and synthesizing data contained in documents" (Bowen, 2009, p. 29). Similar to many other analytical methods in the realm of qualitative research, document analysis involves examining and interpreting data for the purpose of eliciting meaning, gaining understanding, and developing empirical knowledge (Corbin & Strauss, 2008). Document analysis combines "elements of content analysis and thematic analysis" (Bowen, 2009, p. 33). Content analysis involves the process of "organising information into categories" related to the research questions and thematic analysis involves "pattern recognition" (Fereday & Muir-Cochrane, 2006) within the selected data, and "coding and category construction," to "uncover themes pertinent to a phenomenon" (Bowen, 2009, p. 33). Document analysis is often applied to qualitative research in combination with other research methods as a method of triangulation which is "the combination of methodologies in the study of the same phenomenon" (Denzin, 1970, p. 291). However, according to Bowen (2009), it can also be used as a "stand-alone method" (p. 29) as documents may be the "only necessary data source for studies designed within an interpretive paradigm, as in hermeneutic inquiry" (p. 29). In order to glean as much descriptive information in terms of the features of the selected AI curricula for K-12, the use of document analysis from a qualitative stance was pertinent to the research questions already presented.

4.4 « Analytical Framework »

Schwab's (1969) four commonplaces will be used as the analytical framework for data analysis of the selected AI curricula to address the research questions. Schwab (1969) believed that a complete and coherent curriculum requires the articulation of each of the four curriculum "commonplaces": that of the teacher, the student, the subject matter, and the social milieu. These four aspects of education are equally important, and one must never overshadow the others. Schwab (1969) also suggested that the proper relation of these four commonplaces be coordination rather than subordination. Thus, Schwab's theory of commonplaces is used to magnify the importance of each of the commonplaces as well as to emphasize the necessity for cohesion among them.

4.5 « Procedure of Data Analysis »

Structured in the above analytical framework, the analysis will follow three general steps:

> Step 1. Identifying, collecting and reviewing various types of documents on the existing AI curricula, and selecting AI curricula for K-12 as the documents to be analyzed.
>
> Step 2. Describing the selected documents and analyzing them with the help of the software NVivo 12 Pro to identify, describe and categorize phenomena found in the data based on the research questions.
>
> Step 3. Conducting a comparative analysis of the selected documents to identify themes concerning common features and gaps among the selected curricula and to evaluate them through the lens extracted from the theoretical framework.

In step 1, the documents selected for document analysis are the MIT *An Ethics of Artificial Intelligence Curriculum for Middle School Students* (Payne, 2019) from the US, the *Alternate Unit: Artificial Intelligence* curriculum for high school students (Clarke, 2019) from the UK, the *CBSE Artificial Intelligence Curriculum* (Central Board of

Secondary Education , 2019) for Grade 9 from India, and the *Actua's AI Education Handbook* (Actua, 2020) from Canada. These four curricula are all publicly. Of these AI curricula, the curriculum from Canada is more of a different kind than the others as it covers only institutional and programmatic levels and is aimed at educators instead of students.

In step 2, content analysis is used to analyze data. Before exploring the actual techniques of content analysis, it is necessary to review several basic terms. The term "datum" is a "unit of information that is recorded in a durable medium, distinguishable from other data, analyzable by explicit techniques, and relevant to a particular problem" (Krippendorff, 1980, p. 53). According to Saldaña, "a code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (p. 3). The term "category" which is essential to coding units of data refers to "groups of words with similar meanings and/or connotations" (Weber, 1990, p. 37). A theme then refers to "clusters of categories that share some commonality such as reference to a single issue" (Westbrook, 1994, p. 246).

According to Bowen (2009), content analysis is the process of "organising information into categories related to the central questions of the research" (p. 32). Guided by the research questions, the theoretical framework and the analytical framework, the selected AI curricula for K-12 are deductively coded into 4 general categories, namely, subject matter, role of teacher, role of student, and milieu. In each category, data analysis is conducted based on an inductive approach "geared to identifying patterns and discovering theoretical properties in the data" (Bowen, 2009, p. 37). According to Patton (1980), in inductive analysis, the "patterns, themes, and categories of analysis come from the data; they emerge out of the data rather than being imposed on them prior to data collection and analysis" (p. 306).

Coding is the fundamental process in data analysis. According to Strauss (1987), coding does not descriptively paraphrase the notes; instead, it identifies the main categories and the associated subcategories so that all units of data can be categorized according to these codes eventually. This study borrows the coding scheme often used in the grounded theory. Three basic types of coding will be applied in the research to analyze data: open coding, axial coding and selective coding (Corbin & Strauss, 1990). Open coding in qualitative data analysis involves identifying, categorizing and describing phenomena found in the data. Axial coding is defined by Strauss and Corbin (1990) as "a set of procedures whereby data are put back together in new ways after open coding, by making connections between categories (p.96). Open coding and axial coding will be applied to Step 2 to label concepts, define and develop categories based on their properties and dimensions. In this study, open coding is "the interpretive process" in which data are labeled analytically with the purpose of getting new "insights by breaking through standard ways of thinking about or interpreting phenomena reflected in the data" (Corbin & Strauss, 1990, p. 12). In open coding, codes are created to label what elements are included in each of the four categories of the analytical framework (subject matter, role of teacher, role of student, and milieu). Axial coding involves the process of relating open codes to each other and identifying relationships among the codes. In axial coding, categories are created to include closely related codes and construct linkages between different curricula.

In step 3, thematic analysis is applied to the interpretation of data. After axial coding, thematic coding is conducted to generated themes in each of the four general categories of the analytical framework. Thematic analysis is a form of "pattern recognition within the data", with "emerging themes" becoming the categories for analysis (Fereday & Muir-Cochrane, 2006, p. 4). Boyatzis (1998) defined a theme as "a pattern in the information that at minimum describes and organises the possible observations and at maximum interprets aspects of the phenomenon" (p. 161). The process involves a more focused review of the data and then identification of themes through "careful reading and re-reading of the data" (Rice & Ezzy, 1999, p. 258). The selected AI curricula will be examined with a closer look followed by more abstract level of category construction, based on the characteristics of data that appeared in the previous coding, to uncover themes related to the research questions. Selective coding will be used in Step 3 to uncover themes. Selective coding is the process of choosing one category to be the "core category" and all categories are unified around a "core category", and "categories that need further explication are filled-in with descriptive detail" (Corbin & Strauss, 1990, p. 14).

Critical to data analysis is the principle of saturation. According to Westbrook (1994), a category could be considered saturated "when no new information about it develops out of the data" (p. 246). Westbrook (1994) further explained that the continuous assignment of new data to that category becomes unnecessary for the generation of theory (themes in this study) only when a category is as fully understood as possible in all of its ramifications and detail.

Constant comparative method (Glaser & Strauss, 1967) will guide the whole data analysis process in which data will be coded and organized into themes that emerged as the analysis progresses. The constant comparative method involves "joint coding and analysis during the continual review of data in order to gradually form categories" (Westbrook, 1994, p. 246). According to Glaser (1965), by constant comparative method, indicators, concepts and categories are constantly compared from the beginning of analysis and continues till the theory emerges. For this study, constant comparative method is only used in the coding process (open coding to axial coding to selective coding) as the coding scheme borrowed from the grounded theory does not necessarily lead to the discovery of a theory in this study. If new categories were shown in the data under analysis, then the previous data of documents will be analyzed once again to reassure the presence of the categories. Through constant comparison, the underdeveloped categories will have the chance to be filled in and redundant ones narrowed. Only when all the codes from all the documents created a consistent map of addressing the research questions will the processes of data analysis be completed. How does this idea converge or diverge from that of the preceding document? What information is mentioned in both or more documents? How does this aspect connect to other aspects in the same document or different documents? Questions like these remind me that one objective of my data analysis to identify the "similarities, differences, and general patterns" (Bowen, 2008, p. 144). Such comparisons help me guard against bias as well as achieve "greater precision (the grouping of like and only like phenomena) and consistency (always grouping like with like)" (Corbin & Strauss, 1990, p. 9). Figure 2 helps to show the procedure of this study:

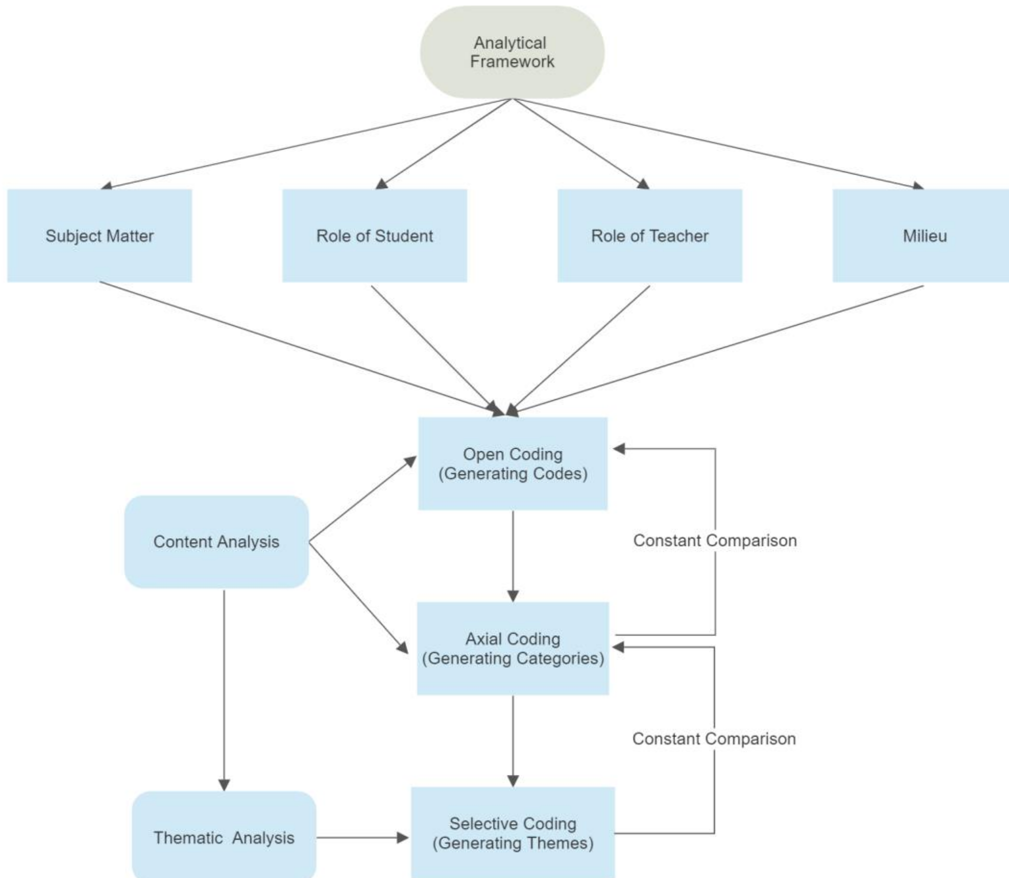

Figure 2: Coding Scheme

4.6 « Ethical Considerations »

According to the TCPS2 (2018), ethics review is not required for "research that is non-intrusive and does not involve direct interaction between the researcher and individuals through the Internet" and "for which there is no expectation of privacy" (p. 16). Examples include uncontrolled public access via the Internet to cyber-material such as documents, records, performances, online archival materials or published third-party interviews. Uncontrolled access means there is no login or password required to access the information, video, etc. The curricula collected as data in my research are all accessible via the Internet and open for attendance by the public. Thus, there are no ethical concerns with the study as it is a study on publicly available written documents via Internet.

4.7 « Limitations »

Limitations occur for all studies, and the study undertaken is limited in several ways. First, because of the nature of an MA study, the data were coded and themes identified in the data by one person and the analysis then discussed with a supervisor. This data analysis process allowed for consistency in the method but failed to provide multiple perspectives from a variety of people with differing expertise. Second, only four AI curricula are analyzed concerning the range of coverage of the study. According to Bowen (2009), gaps or sparseness of documents may be a limitation to document analysis. Usually, limiting the number of documents involved is important in terms of the limited time and funds available to do a study. However, in my case, the availability of existing AI curricula for K-12 would be the main reason, as AI education is a new field of study. However, on the primary stage of AI education research, a study on the existing AI curricula is meaningful in that future research will carry on based on the result of this study. Third, the research only focuses on the content of written documents of the AI curricula. The concerns of conducting document analysis can be that a document may not cover all the necessary information needed to answer the research questions.

However, the first concern may be lessened by having a thorough and deep study on limited documents to extract information needed to address the research questions. A strict analytical process that incorporates evaluative steps and measures such as a clear coding scheme integrated with constant comparative method as elaborated in the methodology section may ensure that the advantages of document analysis outweigh the issues it may arise. I leave the other two concerns to future research.

Chapter 5

5 « Findings of Data Analysis »

The purpose of this chapter is to present the findings of the qualitative document analysis executed during this study. The analysis is based on the first research question:

What are the basic elements of the existing AI curricula for K-12?

In order to address this research question, four sub-questions are addressed:

1. What are the subject matters included in the four selected AI curricula for K-12?
2. What are the roles of the teachers of the four selected AI curricula for K-12?
3. What are the roles of the students of the four selected AI curricula for K-12?
4. What are the milieux of the four selected AI curricula for K-12?

The findings are presented from three layers of interpretations. First, I present a holistic descriptive analysis of each of the selected curriculum. In this step, I create a summary (a table) containing general information about each selected curriculum such as the country and organization that creates the curriculum, the goals of the curriculum, contents, target learners, teaching methods, and teaching environments, etc. Second, I select a sample lesson plan from each curriculum as a focus for detailed illustration. I create a table for each curriculum including general structure, sample instruction, and sample codes I create on the sample instruction. Last, I present and interpret the numeric data that are generated from the data analysis process using NVivo12 Pro to scaffold the descriptive analysis and/or further explore the major elements of each selected curriculum. The findings of data analysis are categorized into themes and within those themes are categories and subcategories inductively coded as discussed in Chapter 4 of this thesis. Many themes emerged during data analysis. As demonstrated in Chapter 4, document analysis is conducted in the analytical framework of Schwab's four commonplaces of curriculum: the subject matter, the teacher, the student, and the social milieu. The structures of codes, categories, and themes are illustrated in Figure 3 to Figure 7.

As subject matter is the most complicated part of the findings to present, I create two charts instead of one to better illustrate the structure of this part. Two general themes are generated in this part, namely, "social ethical subject" and "technical subject." Figure 3 and Figure 4 illustrate the codes, categories, and themes generated on "social ethical subject" and "technical subject" respectively.

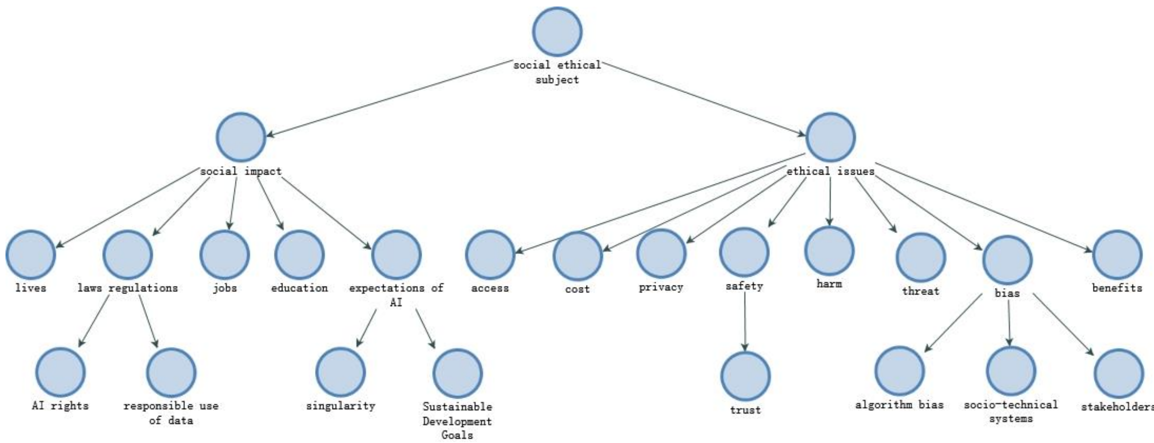

Figure 3: Categories of Codes on Social Ethical Subject

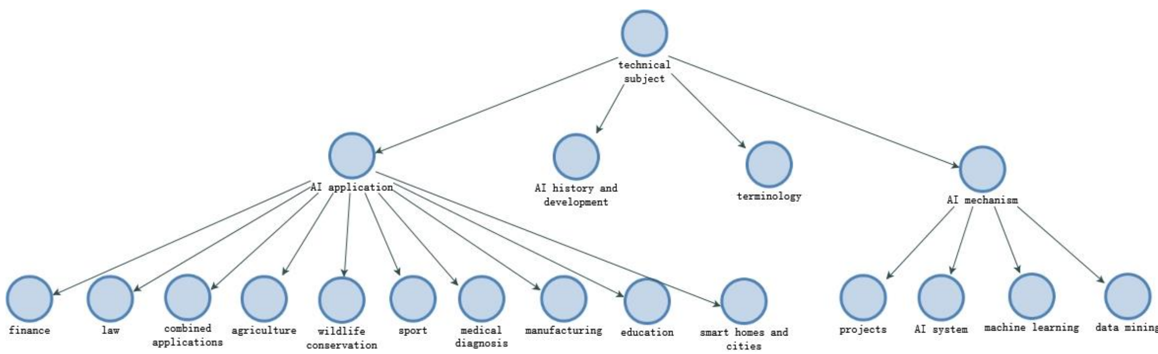

Figure 4: Categories of Codes on Technical Subject

In content analysis, I form 6 categories of codes on the subject matter, namely "social impact", "ethical issues", "AI application", "AI history and development", "AI mechanism", "terminology." In the thematic analysis, two general themes ("social ethical subject" and "technical subject") are generated under the umbrella of subject matter. Under the theme of "social ethical subject", there are two categories: "social impact" and "ethical issues." Under the theme of "technical subject", there are four categories: "AI history and development", "terminology", "AI application", and "AI mechanism."

Figure 5 illustrates the codes, categories and themes generated on role of teacher.

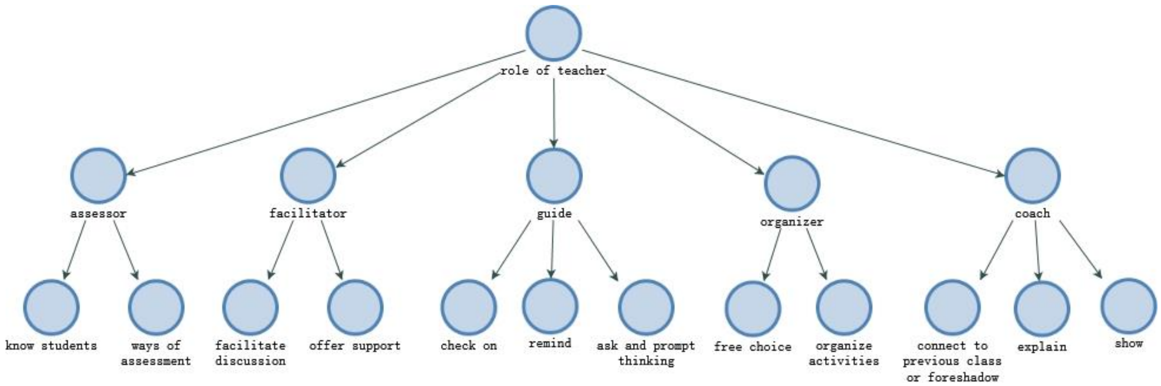

Figure 5: Categories of Codes on Role of Teacher

Five themes are generated on the roles of the teacher. They are "assessor", "coach", "guide", "organizer" and "facilitator." Under "assessor", there are two categories: "know students" and "ways of assessment." Under "coach", there are three categories: "connect to previous lesson or foreshadow", "explain" and "show." Under "guide", there are three categories: "ask and prompt thinking", "remind" and "check on." Under "organizer", there are two categories: "free choice", and "organize activities." Under "facilitator", there are two categories: "facilitate discussion", and "offer support."

Figure 6 illustrates the codes, categories and themes generated on role of student.

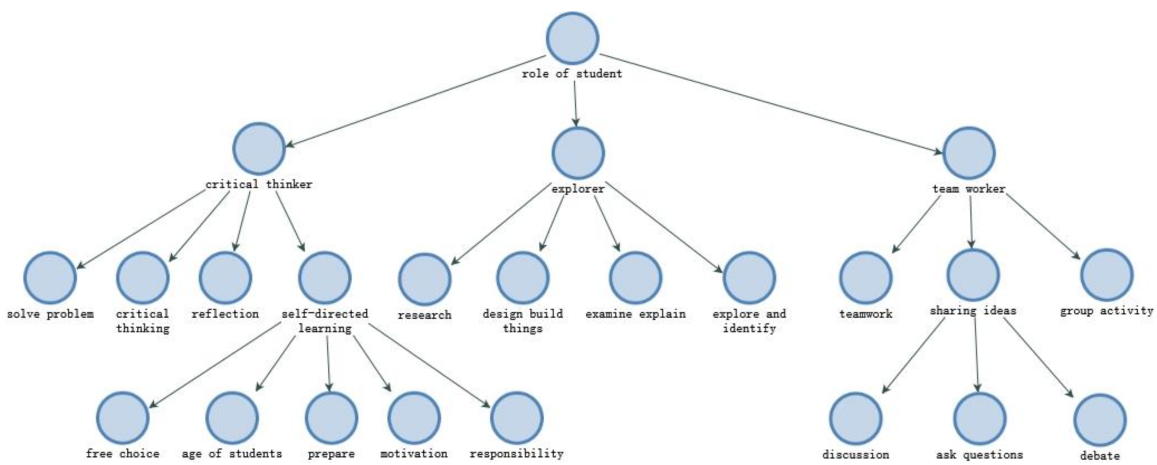

Figure 6: Categories of Codes on Role of Student

I form 3 themes on the roles of the student. They are "critical thinker", "explorer", "team worker." Under the theme of "critical thinker", there are four categories: "critical thinking", "reflection", "self-directed learning" and "solve problem." Under the category of "self-directed learning", there are five subcategories: "age of students", "free choice", "motivation", "prepare", and "responsibility." Under the theme of "explorer", there are four categories: "design build things", "examine explain", "explore and identify" and "research." Under the theme of "team worker", there are three categories: "group activity", "sharing ideas", and "teamwork." Under the category of "sharing ideas", there are three subcategories: "ask questions", "debate", and "discussion."

Figure 7 illustrates the codes, categories and themes generated on milieu.

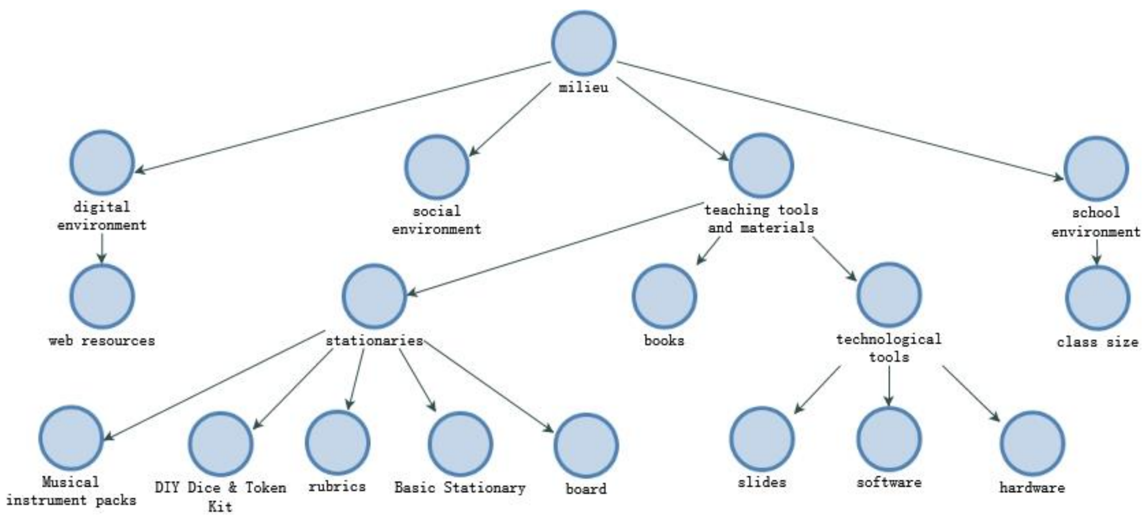

Figure 7: Categories of Codes on Role of Milieu

I form 4 themes from codes on the milieu. They are "digital environment", "teaching tools and materials", "social environment", "school environment." "Digital environment" is separately listed as a category because it reflects to what extent a curriculum makes uses of open online sources as an overall context of learning. Under the theme of "teaching tool and materials", there are three categories: "stationaries", "book" and "technical tools." Under the theme of "digital environment" and "school environment", "web resources", and "class size" are categories respectively. Under the category of "stationery", there are five subcategories: "rubrics", "basic stationery", "board", "DIY dice and token kit", and "Musical instrument packs." Under the category of "technical tools", there are three subcategories: "hardware", "slides", and "software."

The following analysis will be based on the above charts.

5.1 « US: *An Ethics of Artificial Intelligence Curriculum for Middle School Students* »

The curriculum from the US goes from the programmatic level of curriculum to the classroom level with its emphasis on classroom activities. This section presents the findings of data analysis in three layers as mentioned earlier in this chapter.

5.1.1 General Information

Table 2 provides general information on the curriculum from the US.

Table 2: General Information on *An Ethics of Artificial Intelligence Curriculum*

Curriculum	An Ethics of Artificial Intelligence Curriculum for Middle School Students
Created/supported by	MIT Media Lab, US
Goals	Teaching about the ethics of AI
Contents	1.AI bingo (AI system) 2.Algorithms as opinions 3.Ethical matrix 4.Intro to supervised machine learning & algorithmic bias 5.Speculative fiction (impacts of AI) 6.YouTube scavenger hunt (recognize AI systems) 7.YouTube redesign 8.YouTube Socratic seminar
Students	Grades 5th-8th recommended
Methods	Not stated
Environment	Mainly unplugged

With a focus on the ethics of AI, the curriculum from the US lists five detailed objectives as follows:

1. Understand the basic mechanics of artificial intelligence systems.
2. Understand that all technical systems are socio-technical systems.
3. Recognize there are many stakeholders in a given socio-technical system and that the system can affect these stakeholders differentially.
4. Apply both technical understanding of AI and knowledge of stakeholders in order to determine a just goal for a socio-technical system.
5. Consider the impact of technology on the world. (p. 7-9)

The curriculum from the US includes eight activities, each lasting from 30 minutes to about four hours. The most common sections for each activity are “Description”, “Slides’, and a detailed “Teacher Guide” which may include “Teaching point”, “Materials Required”, “Connection”, “Discussion”, etc. The curriculum from the US is for middle school students (Grades 5th-8th). Although the curriculum from the US doesn’t explicitly state its pedagogy, it describes the eight activities and a final project which is based on the activities. The curriculum from the US designs unplugged settings for seven out of eight activities (activities without the use of any digital technology) to fit into traditional classroom settings. There is one activity that has both plugged and unplugged versions and one plugged activity.

5.1.2 Sample Activity/Lesson Plan

One important feature of the curriculum from the US is that there is no unified form for the eight activities in their format, length, teaching procedures, etc., so it is impossible to choose a sample that can represent the others. Therefore, I chose “Introduction to Supervised Machine Learning and Algorithmic Bias” as it is the most inclusive, descriptive and the longest lesson plan of the curriculum. Table 3 provides information on this sample activity in the curriculum from the US.

Table 3: Sample Activity of *An Ethics of Artificial Intelligence Curriculum*

	General information	Examples quotes	Initial codes
Name	Introduction to Supervised Machine Learning and Algorithmic Bias	Introduction to Supervised Machine Learning and Algorithmic Bias	supervised machine learning, algorithmic bias
Duration	About 3 hours		
Subject matter	Image classification	Image classification	classification
Project/activity	Build a cat-dog classifier (given a biased dataset)	Students are asked to build a cat-dog classifier but are unknowingly given a biased dataset.	classifier, bias, dataset
Milieu	Google’s Teachable Machine tool Materials Required	By exploring Google’s Teachable Machine tool Slides Worksheet x 3 Chromebooks + chargers Dog/cat cards Musical instrument packs	digital, environment, slides basic stationery, computer

Teaching process	1.Connection: teacher prompts thinking by asking what the three components of AI are learned in previous lesson (dataset, learning algorithm, prediction).	Connection: Remember yesterday when we discussed the definition of AI? What were the three components we talked about?	connection to previous lesson
	2. Introduction to supervised machine learning, with a focus on classification, using everyday example as analogy to explain. Mentioning concept of “regression”	Today we are going to talk a little bit more about training datasets and dig into the “learning” algorithm aspect of AI a little more. Particularly, we’re going to talk about one very common form of artificial intelligence called supervised machine learning. With regression, instead of trying to predict a category a new piece of data belongs to, you are trying to predict some numerical value for that data.	data, supervised machine learning, regression
	3. Teacher demos the Teachable Machines, students train and test datasets	Let’s build our own classifiers now. Let me demo Teachable Machines to you now. Go around and prompt students. I want you to build a machine that classifies cats and dogs.	design build things, show, check on, offer support
	4.Discussion on algorithmic bias on data	Prompt Discuss When algorithms, specifically artificial intelligence systems, have outcomes that are unfair in a systematic way, we call that algorithmic bias	Ask and prompt thinking, discussion, data, algorithms bias
	5. Teacher plays Gender Shades facial detection video; students discuss on how algorithmic bias can occur.	Now I want us to take some time to watch a video about how it can happen in the real world. Discuss	Show, discussion

As shown in Table 3, the curriculum from the US covers the subject matter of “image classification” in the activity entitled “Introduction to Supervised Machine Learning and Algorithmic Bias.” The process of teaching is stated in the teacher’s guide section of the lesson plan. The teacher in the curriculum from the US starts the lesson by asking questions to lead students to review knowledge learned from the previous lesson, paving for new knowledge by linking it to previous knowledge. In NVivo coding, it is labeled as "connecting to previous lesson" in the category of "role of teacher." In the second step, the curriculum from the US introduces the intent of learning "supervised machine learning" with a focus on classification, using an everyday example as an analogy to explain new concepts. In NVivo coding, I label these codes as "data", "supervised machine learning", "regression" in the category of "subject matter." The concepts concerning machine learning are explained by the teacher. Then the concept of "regression" is introduced by the teacher as follows:

> We're going to focus on classification problems today, but regression problems are very similar. With regression, instead of trying to predict a category a new piece of data belongs to, you are trying to predict some numerical value for that data. For example, you might be trying to predict what the temperature will be tomorrow. (p. 28-29)

The unfamiliar terminology "regression" is brought to students with a daily example. In the third step, the curriculum from the US applies Google's Teachable Machine as the tool for their teaching. This is labeled as "digital environment" and other "Materials Required" is labeled as "slides", "basic stationery", "computer" in the category of "Milieu." When students edit images, the teacher in the curriculum from the US demos the Teachable Machines, then let the students train and test the datasets. The teacher checks on and offers support as students work through the activity. The students' activity is labeled as "design build things" in the category of "role of student", the teacher's teaching is labeled as "show", "check on", "offer support" in the category of "role of teacher." In the fourth step, the curriculum from the US focuses on students' reflection by promoting class discussion on the algorithmic bias on data. The teacher's role is labeled as "ask and prompt thinking" and students' role is labeled as "discussion." In the fifth step, the curriculum from the US links knowledge on AI mechanism with its real-world application focusing on the ethics of AI. The teacher in the curriculum from the US plays a facial detection video entitled "Gender Shades" to the class, then promotes students' discussion on how algorithmic bias can occur. Codes like "show" and "discussion" label "role of teacher" and "role of student" respectively.

In the following part, the numeric data that are generated from the NVivo coding are presented within the analytical framework of Schwab's (1969) four commonplaces of curriculum: the teacher, the student, the subject matter, and the milieu.

5.1.3 Subject Matter

To address the sub-question of what subject matters are included in the selected AI curricula, the subject matters of the curriculum from the US are analyzed and presented in this part. I generated 93 codes in the 94 pages curriculum from the US using Nvivo 12 Pro.

Figure 8 shows the coverage percentage of codes (which indicates how much of the source content is coded at this node) on the subject matter of the AI curriculum form the US (MIT Curriculum).

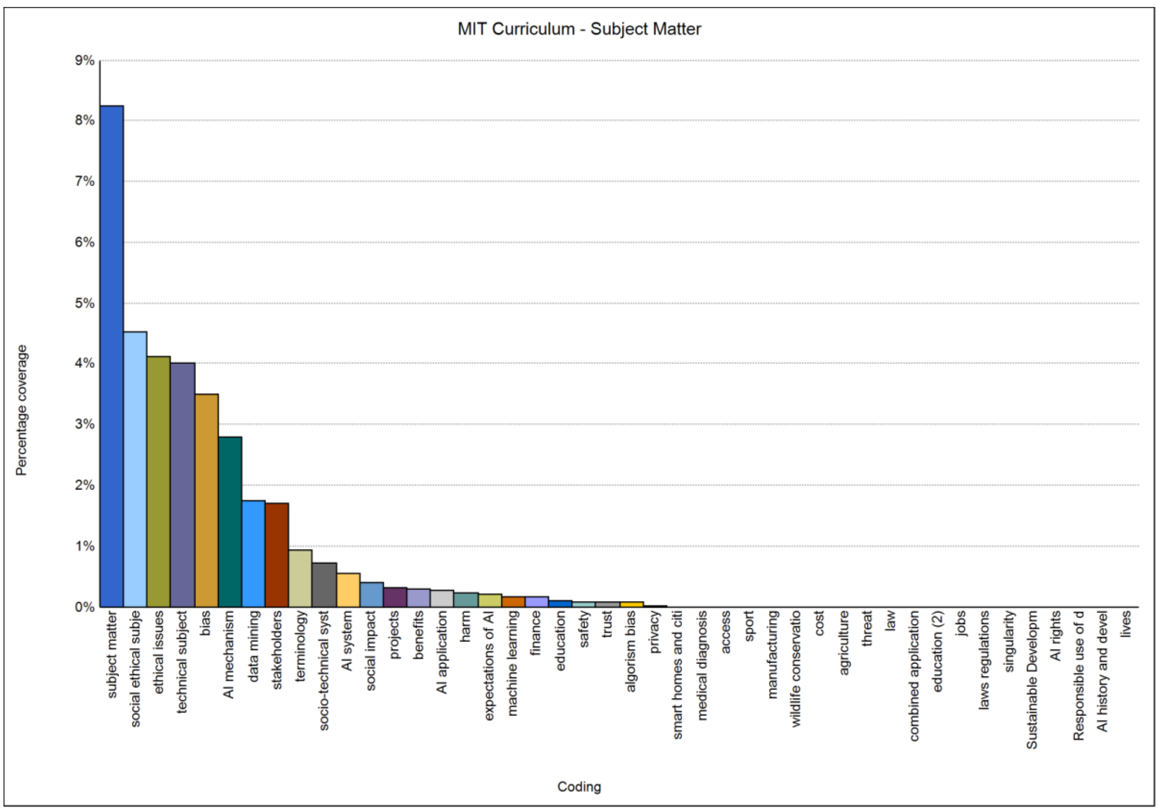

Figure 8: Coverage Percentage of Codes on Subject Matter of *An Ethics of Artificial Intelligence Curriculum*

"Subject Matter" counts for 8.25% in coverage percentage of the curriculum from the US. Two themes appear here: "Social ethical subject" counting for 4.54% and "technical subject" counting for 4.02%. Under the theme of "Social ethical subject", "ethical issues" counts for 4.13%, making it the most frequently coded category. The other category under the same theme, "social impact", counts for 0.41%, which is much less in coverage percentage. In the category of "technical subject", "AI mechanism" (2.80%) becomes the largest subcategory, followed by "terminology" (0.95%), and "AI application" (0.27%). The curriculum from the US does not include "AI history and development" as its subject matter. The above data indicate that the curriculum from the US puts more emphasis on "social ethical subject" especially on "ethical issues."

A detailed illustration of the contents of the subcategory of "ethical issues" and "social impact" shows that under the umbrella of "ethical issues", the curriculum from the US covers a quite a wide ranges of subjects, such as "bias" (which covers "algorism bias", "socio- technical systems" and "stakeholders"), "benefits", "harm" "safety" (which covers the issue of "trust"), "privacy" (see Figure 3 for the structure of themes and categories). Codes on "bias" count 3.51%, becoming the most frequently mentioned subject in the category of "ethical issues" (in which the codes on "stakeholders" alone count for 1.71%, followed by "social ethical systems" counting for 0.73%, and "algorithm bias" counting for 0.08%). In the subcategory of "social impact", the only type of code is on "expectations of AI", counting for 0.22%. The above data indicate that the curriculum from the US focuses on "bias" as the subject matter.

A detailed illustration of the contents of the theme of "technical subject" shows that the curriculum from the US covers a certain range of subjects, such as "AI mechanism" (which covers "data mining", "AI system", "projects", and "machine learning"), "terminology", "AI application" (which covers "finance" and "education") (see Figure 4 for the structure of themes and categories). Codes on "AI mechanism" (2.80%) top the categories in "technical subject" (in which the codes on "data mining" alone count for 1.76%, followed by "AI system" counting for 0.56%, "projects" counting for 0.32%, and "machine learning" counting for 0.16%). In the category of "AI application", only two types of codes are generated, namely "education" and "finance" counting for 0.11% and

0.16% respectively. “Terminology” counts for 0.95%, which covers limited terms such as “algorithm”, “regression model”, “classification”, “algorithm bias” on the list. The above data indicate that the curriculum from the US focuses on “data mining” as the technical subject matter. However, it covers limited information on AI applications and covers limited terminologies. The theme of AI history and development is not covered in the curriculum from the US.

5.1.4 Role of Teacher

To address the sub-question of what the roles of the teacher of the selected AI curricula for K-12 are, 144 codes were generated on the role of the teacher. Figure 9 shows the structure of codes, categories and themes on the role of teacher I generated from data analysis.

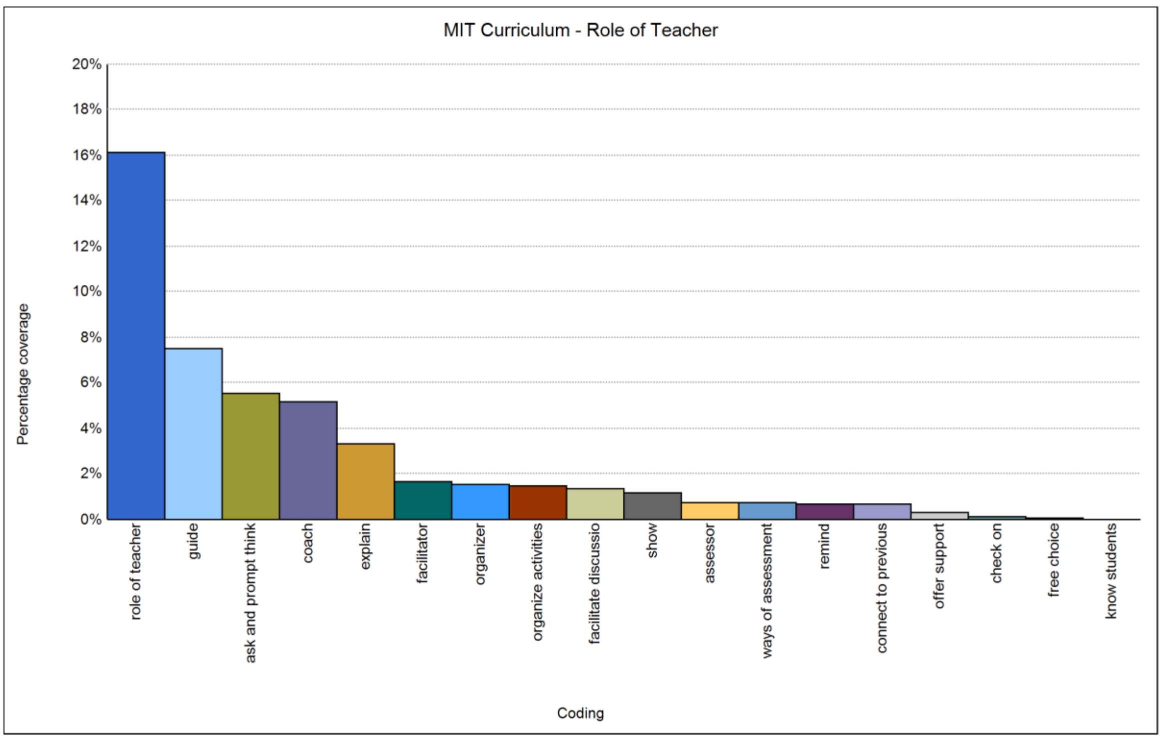

Figure 9: Coverage Percentage of Codes on Role of Teacher of *An Ethics of Artificial Intelligence Curriculum*

Codes on the role of teacher count for 16.12% in coverage percentage in the curriculum from the US. I generated 5 themes from data analysis, namely, “guide”, “coach”, “facilitator”, “organizer”, and “assessor.” The curriculum from the US covers a wide range of themes and categories of “role of teacher” (see Figure 5 for the structure of themes and categories). Codes on “guide” (7.53%) top the themes in “role of teacher” (in which the codes on “ask and prompt thinking” alone count for 5.57%, followed by “remind” counting for 0.67%, “check on” counting for 0.12%). Following the theme of “guide” are the theme of “coach” counting for 5.16%, the theme of “facilitator” counting for 1.65%, the theme of “organizer” counting for 1.51%, and the theme of “assessor” counting for 0.76%.

The above data indicate that the role of a teacher in the curriculum from the US focuses on “guide” and “coach” and the teacher teaches mainly by asking and prompting thinking and explaining. However, it covers limited information on the teacher’s role as an “assessor”. “Know students” is not covered in the curriculum from the US.

5.1.5 Role of Student

To address the sub-question of what the roles of the students of the selected AI curricula for K-12 are, I generated 103 codes on the role of the students in the curriculum from the US. Figure 10 shows the coverage percentage of codes on role of student generated from data analysis.

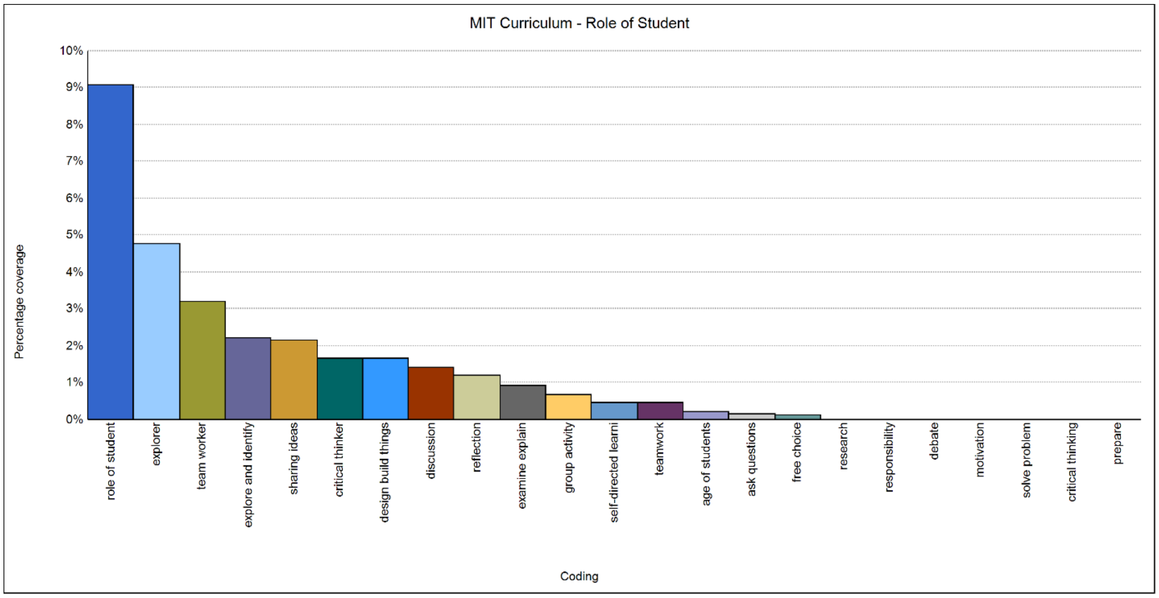

Figure 10: Coverage Percentage of Codes on Role of Student of *An Ethics of Artificial Intelligence Curriculum*

Codes on the role of student count for 9.06% in coverage percentage in the curriculum from the US. I generated 3 themes from thematic analysis, namely, “explorer”, “team worker”, and “critical thinker.” The curriculum from the US covers a wide range of themes and categories of “role of student” (see Figure 6 for the structure of themes and categories). Codes on “explorer” (4.78%) top the themes in “role of student” (in which the codes on “explore and identify” count for 2.21%, followed by “design build things” counting for 1.65%, “examine explain” counting for 0.92%). The second frequent theme is “team worker” counting for 3.21% (in which the codes on “sharing ideas” count for 2.15%, followed by “group activity” counting for 0.68%, and “teamwork” counting for 0.45%). The theme of “critical thinker” counts for 1.67% (in which the codes on “reflection” count for 1.20%, followed by “self-directed learning” counting for 0.47%).

The above data indicate that the role of students in the curriculum from the US focuses on “explorer.” The students learn mainly by exploring and identifying, sharing ideas with peers, and designing and building things.

5.1.6 Milieu

To address the sub-question of what the milieux of the selected AI curricula for K-12 are, I generated 50 codes from data analysis on the curriculum from the US. Figure 11 shows the coverage percentage of codes on the milieu

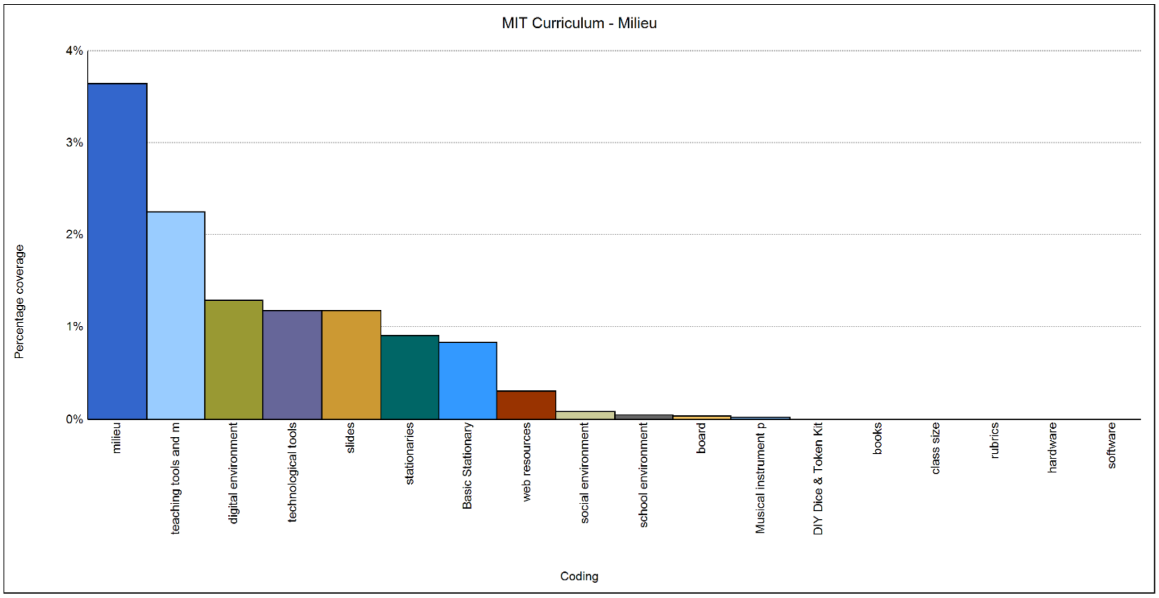

Figure 11: Coverage Percentage of Codes on Milieu of *An Ethics of Artificial Intelligence Curriculum*

Codes on milieu count for 9.06% in coverage percentage in the curriculum from the US. Four themes are generated from data analysis, namely, “social environment”, “school environment”, “teaching tools and materials” and “digital environment.” The curriculum from the US covers a wide range of themes and categories of “milieu” (see Figure 7 for the structure of themes and categories). Codes on “teaching tools and materials” (2.25%) becomes the most frequent group (in which the codes on “technical tools” and its subcategory “slides” count for 1.18%, followed by “stationery” counting for 0.90%). The second frequent theme is the “digital environment” which counts for 1.30%. The themes of “social environment” and “school environment” count for 0.09% and 0.05% respectively.

The above data indicate that the milieu in the curriculum from the US focuses on "teaching tools and materials" in which slides serve as the major part of teaching materials and stationery serves as the teaching tools. This is consistent with the design of mainly unplugged activities of the curriculum from the US.

5.2 « UK: *Alternate Unit: Artificial Intelligence* »

Similar to the curriculum from the US, the curriculum from the UK also goes from the programmatic level of curriculum to classroom level with its emphasis on daily lesson plans for classroom activities.

5.2.1 General information

Table 4 provides general information on the curriculum from the UK.

Table 4: General Information on *Alternate Unit: Artificial Intelligence*

Curriculum	Alternate Unit: Artificial Intelligence
Created/supported by	NVIDIA, Scan Computers International Ltd, UK
Goals	Demystify AI
Contents	Day1 What is Artificial Intelligence? Day2 Smart cities, homes, and schools Day3-4 Smart city, home, and school design Day5-7 What is a neural network? Forward propagation and backward propagation Day 8-10 Image Recognition Activity (on NVIDIA platform) Day11 Areas that AI is changing Day12 Algorithmic bias Day13 Accessible AI Day14-15 AI and the world of work; moral and ethical dilemmas Day16-17 Future News! AI images and narratives design and presentations Day18-19 Final project: "AI for Everyone" Day20 Final project presentations
Students	Grades 9th-12th recommended
Methods	Not stated
Environment	Mainly plugged

The AI curriculum from the UK aims to "demystify the topic of AI" in a broad sense, "with students gaining an understanding of terminology such as machine learning, deep learning, and other AI-associated terminology. Students will gain knowledge and skills while considering the social, moral, and ethical impacts of AI systems and usage" (p. 3).

Guided by these goals, the content contains 12 units (daily lesson plans) covering 4 major topics:

1. Background of Artificial Intelligence
2. Everyday usage of AI systems (Smart cities, homes, and schools)
3. Building and applying AI systems (neural network, image recognition, Algorithmic bias, Forward propagation, and backward propagation)
4. Societal impacts (AI images, ethical dilemmas) (p. 3)

Each lesson plan has a unified form of teaching procedure: general rubrics on "Topic Description", "Objectives", "Outline of the Lesson", "Student Activities", and "Resources", followed by a detailed "Teaching/Learning Strategies" instruction.

5.2.2 Sample Activity/Lesson Plan

The curriculum from the UK has evenly developed lesson plans. I choose "Instructional Days: 8–10" as a sample to illustrate because it deals with the same subject matter – supervised image classification as the curriculum from the US does. Table 5 provides the information on this sample lesson plan in the curriculum from the UK.

Table 5: Sample Lesson Plan on *Alternate Unit: Artificial Intelligence*

	General information	Examples quotes	Example codes
Name	Instructional Days: 8–10		
Duration	165 minutes		
Subject matter	Image classification (with an emphasis on mechanism of neural network)	Image classification	classification
Project /activity	Train a deep neural network on image recognition	Image classification with DIGITS (120 minutes)	classification, neural network, image speech recognition
Milieu	NVIDIA environment via a cloud server (Amazon Web Services) to access DIGITS (a	https://courses.nvidia.com/ courses/course-v1: DLI+L-FX-01+V1/about Teachers PowerPoint Days 8–10	Digital environment, slides

	front-end tool of common AI frameworks)	(for teacher reference and background knowledge only)	
Teaching process	1.Journal Entry: teacher prompts thinking by comparing machine learning with human intelligence	Journal Entry: When you look at a cat or a dog, how do you know which is which? What process did you go through to decide? Were you even aware that you went through a process? Have students share their thoughts with an elbow partner.	ask and prompt thinking, sharing ideas
	2.Introduction to image classification activity: teacher clarifies intent of the activity and links new knowledge (data training) with previous knowledge (neural network)	Remind students that in the first lesson of this unit they discussed the term “deep learning.” Explain to students that in this activity they will learn to train a neural network using clean, labeled data.	remind, connection to previous lessons, explain, discussion, design build things, deep learning, neural network, data
	3.Image classification with DIGITS: students work in the NVIDIA environment to train a neural network to recognize images	Have students work in pairs. Have a discussion with the class about the connection between CPU (discussed in unit one) and GPU. Ask students what an image is made up of. Remind students that many computer images are comprised of pixels. Draw links with Unit 1 when they edited images. Explain that each pixel has numerical values attached and due to this we can process anything we can digitize i.e. convert to numbers. As students work through the activity offer support to pairs and ensure they are understanding the terms from the terminology slide of the Teachers PowerPoint.	teamwork, discussion, ask and prompt thinking, remind, explain, offer support, terminology
	4.Thoughts on data: teacher prompts thinking on issues about data	In groups of 3–4, ask students to consider how much data is required to make the neural network accurate. Have students record responses on flipchart paper. Have students share their responses with the whole class and discuss.	teamwork, ask and prompt thinking, reflection, sharing ideas, basic stationery
	5.Deployment: prompt thinking on students	Have the groups discuss ways in which they think this technology	discussion, AI application,

	discuss about application of AI, combines with mechanism of AI with its applications.	can be utilized. Have each group share their thoughts with the whole class.	sharing ideas

As shown in Table 5, the curriculum from the UK has a similar lesson plan with the curriculum from the US on the same topic on “image classification.” The process of teaching is stated in the “Teaching/Learning Strategies” section. The curriculum from the UK begins with a simple question “When you look at a cat or a dog, how do you know which is which?” (p. 16) which sets a relaxing atmosphere in the classroom, followed by more thought-provoking questions such as “What process did you go through to decide?’ “Were you even aware that you went through a process?” (p. 16). Students are encouraged to share their ideas on the questions. In NVivo coding, codes such as “ask and prompt thinking” are generated in the “role of teacher” category, and codes such as “sharing ideas” are generated in the “role of student” category. In the second step, the teacher in the curriculum from the UK clarifies the intent of the “image classification activity” and links the new knowledge on “data training with neural network” to the previous lesson on “simulating a deep learning neural network” (p. 16), to guide students to explore on how machines “recognize” an image like a cat or a dog. In NVivo coding, these are labeled as “connecting to previous lesson”, “remind” and “explain” in the category of “role of teacher” ; “discussion”, “design build things” in the category of “role of student”; “deep learning”, “neural network”, “data” in the category of “subject matter.” In the third step, students in the curriculum from the UK work in the NVIDIA environment via Amazon Web Services (a cloud server) to access DIGITS (a front-end tool of common AI frameworks). When students edit images, the teacher in the curriculum from the UK links previous knowledge about CPU (discussed in unit one) with GPU (new knowledge) and reminds students that computer images are comprised of pixels. The teacher explains that “each pixel has numerical values attached and due to this we can process anything we can digitize i.e., convert to numbers” (p. 17), giving a clearer explanation of new concepts. The teacher in the curriculum from the UK offers support as students work through the activity. The students’ activity is labeled as “teamwork” and “discussion” in the category of “role of student”, and the teacher’s teaching action is labeled as “ask and prompt thinking”, “remind”, “explain”, “offer support” in the category of “role of teacher.” Code like “terminology” belongs to the category of “subject matter.” In the fourth step, the curriculum from the UK has students record responses on flipchart paper and share their responses with the whole class. “Role of teacher” has codes such as “ask and prompt thinking”, and “role of student” has codes like “teamwork”, “reflection”, “sharing ideas”. Code like “basic stationery” belongs to the category of “milieu.” On the fifth step, the curriculum from the UK links knowledge on AI mechanism with its real-world application by discussing the application of AI in a broad sense. The students’ activity is labeled as “discussion”, and “sharing ideas” in the category of “role of student.” Code like “AI application” belongs to the category of “subject matter.”

5.2.3 Subject Matter

To address the sub-question of what subject matters are included in the selected AI curricula, the subject matters of the UK AI curriculum are analyzed and presented in this part. I generated 228 codes in the 40 pages curriculum from the UK using NVivo 12 Pro.

Figure 12 shows the coverage percentage of codes on the subject matter of the curriculum from the UK.

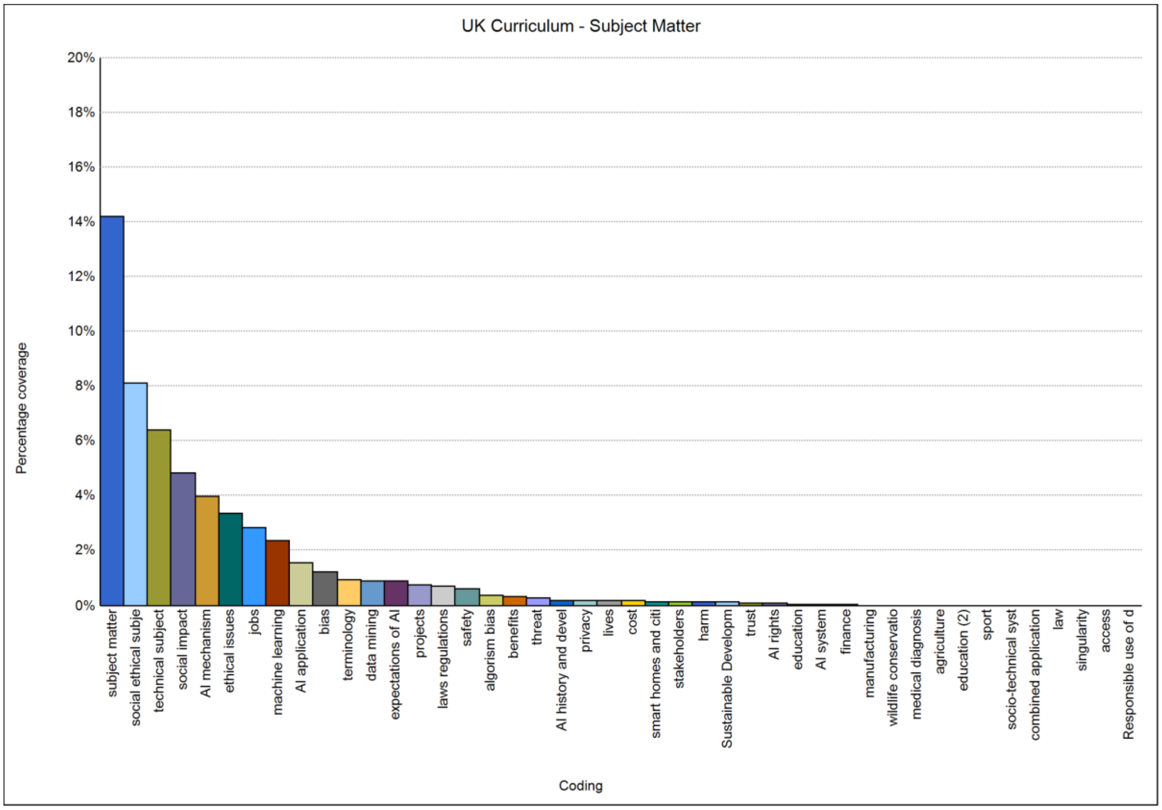

Figure 12: Coverage Percentage of Codes on Subject Matter of *Alternate Unit: Artificial Intelligence*

“Subject Matter” counts for 14.20% in the curriculum from the UK. Its two themes, “Social ethical subject” and “technical subject” count for 8.15% and 6.41% respectively. Under “Social ethical subject”, “social impact” counts for 4.86%, making it the most frequent coding category on the category level. The other category, “ethical issues”, counts for 3.35%. In the category of “technical subject”, “AI mechanism” (3.98%) becomes the largest category, followed by “AI application” (1.58%), “terminology” (0.95%), and “AI history and development” (0.18%). The above data indicate that the curriculum from the UK covers a wide range of subject matters in its content.

A detailed illustration of the contents of the subcategory of “ethical issues” and “social impact” shows that under the umbrella of “ethical issues”, the curriculum from the UK covers quite a few ranges of subjects, such as “bias” (which covers “algorism bias”, and “stakeholders”), “safety”(which covers the issue of “trust”) “benefits”, “threat”, “privacy”, “cost”, and “harm” (see Figure 3 for the structure of categories). Codes on “bias” count 1.22% in coverage percentage, making “bias” the most frequently mentioned subject in the category of “ethical issues” (in which codes on “algorithm bias” count for 0.37%, followed by “stakeholders” counting for 0.16%, and “social technical system” is not covered). In the category of “social impact”, “jobs”, counting for 2.83%, tops the list, followed by “expectations of AI” (0.90%), “laws and regulations” (0.73%) (which includes “AI rights”, counting for 0.09%), “lives” (0.18%), and “education” 0.04%. The above data indicate that the curriculum from the UK focuses on “bias” as the social ethical subject matter.

A detailed illustration of the contents of the theme of “technical subject” shows that the curriculum from the UK covers a wide range of technical subjects, such as “AI mechanism” (which covers “machine learning”, “data mining”, “projects”, “AI system”) “terminology”, “AI application” (which covers “smart home and schools”, “finance” and “manufacturing”, “wildlife conservation”, “medical diagnosis”) (see Figure 4 for the structure of themes and categories). Codes on “AI mechanism” (3.98%) top the categories in “technical subject” (in which the codes on “machine learning” alone count for 2.39%, followed by “data mining” counting for 0.92%, “projects” counting for 0.78%, and “AI system” counting for 0.04%). In the category of “AI application”, five types of codes are generated, namely “smart home and schools” (0.17%), “finance” (0.03%), “manufacturing” (0.02%), “wildlife conservation” (0.02), “medical diagnosis” (0.02%). “Terminology” counts for 0.95%, which covers a wide range of terms such as “reinforcement learning”, “Internet of things”, “artificial intelligence”, “algorithm”, “automation”, “classification” on the list. The above data indicate that the curriculum from the UK is a well-balanced curriculum in terms of subject matter. However, it covers limited information on AI applications.

5.2.4 Role of Teacher

To address the sub-question of what the roles of the teachers of the selected AI curricula for K-12 are, I generated 182 codes on the role of the teacher. Figure 13 shows the coverage percentage of codes on the role of the teacher.

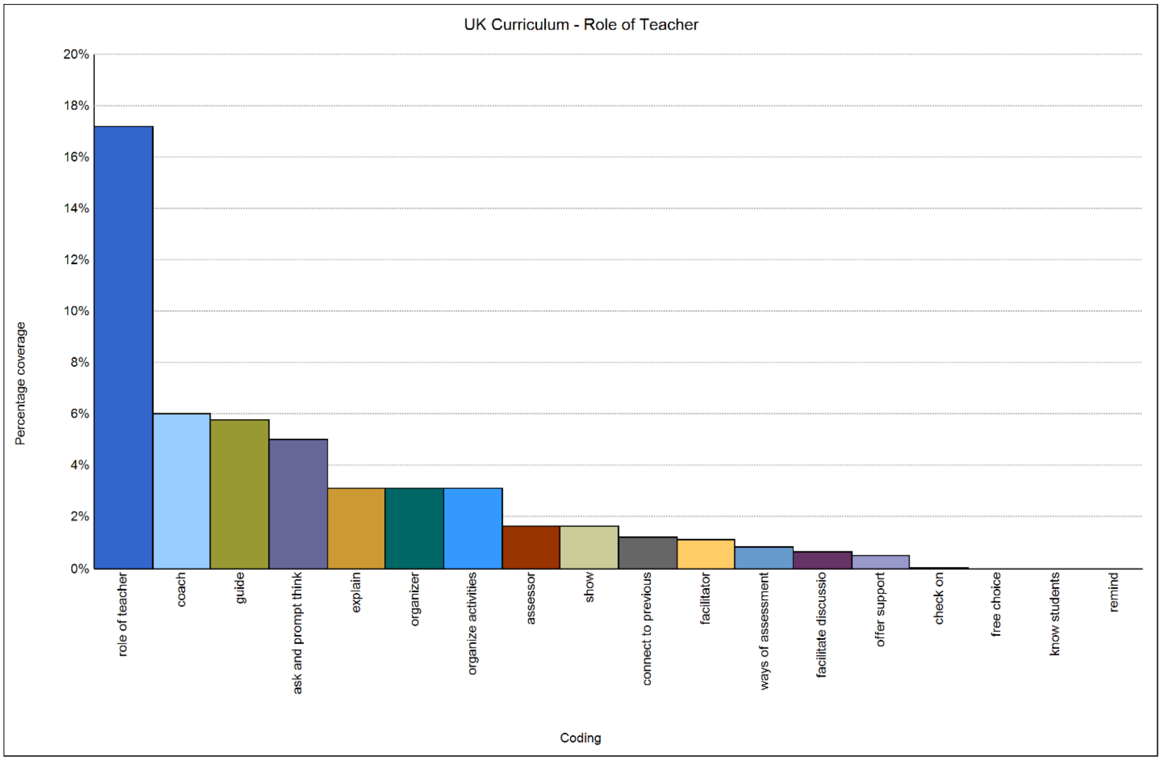

Figure 13: Coverage Percentage of Codes on Role of Teacher of *Alternate Unit: Artificial Intelligence*

"Role of teacher" counts for 17.18% in coverage percentage. I generated 5 themes from data analysis, namely, "guide", "coach", "facilitator", "organizer" and "assessor". The curriculum from the UK covers a wide range of themes and categories of "role of teacher" (see Figure 5 for the structure of themes and categories). Codes on "coach" (6.05%) top the themes in "role of teacher" (in which the codes on "explain" alone count for 3.13%, followed by "show" counting for 1.66% and "connect to previous lesson" counting for 1.26%). "Guide" (5.78%) comes second (in which the codes on "ask and prompt thinking" alone count for 5.04%, followed by "check on" counting for 0.03%). Following are the theme of "organizer" counting for 3.11%, the theme of "assessor" counting for 1.68%, and the theme of "facilitator" counting for 1.14%.

The above data indicate that the role of a teacher in the curriculum from the UK focuses on "coach" and "guide" and the teacher teaches mainly by asking and prompting thinking, explaining, and organizing activities.

5.2.5 Role of Student

To address the sub-question of what the roles of the students of the selected AI curricula for K-12 are, I generated 205 codes on role of the student in the curriculum from the UK. Figure 14 shows the coverage percentage of codes on the role of student.

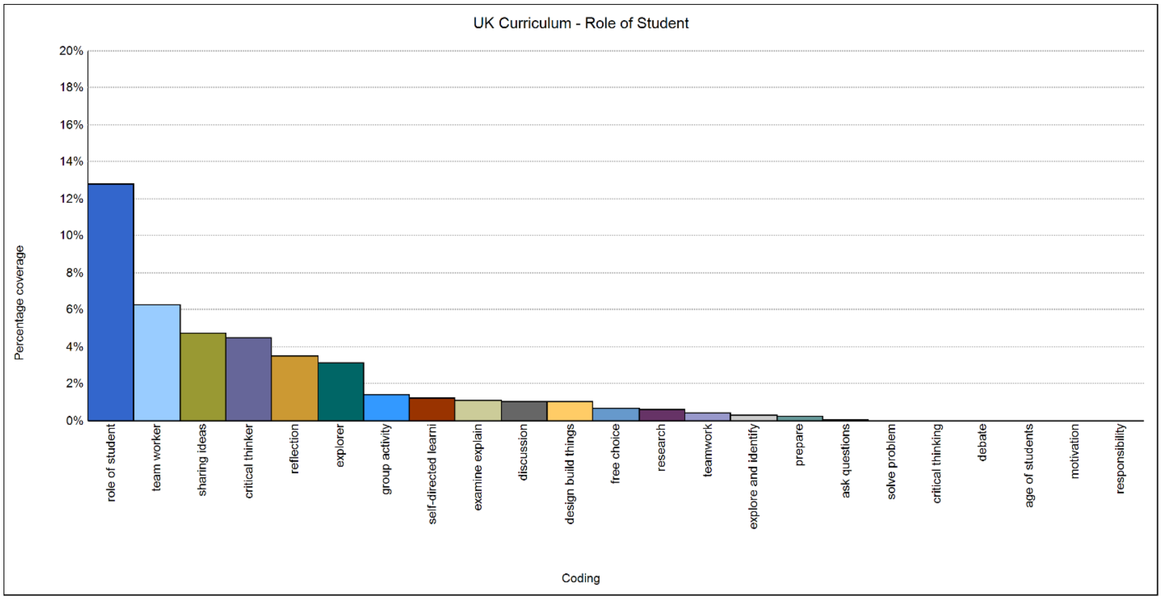

Figure 14: Coverage Percentage of Codes on Role of Student of *Alternate Unit: Artificial Intelligence*

"Role of student" counts for 12.81% in coverage percentage. Three themes were generated from data analysis, namely, "explorer", "team worker", and "critical thinker". The curriculum from the UK covers a wide range of themes and categories of "role of student" (see Figure 6 for the structure of themes and categories). Codes on "team worker" (6.26%) top the themes in "role of student" (in which the codes on "sharing ideas" alone count for 4.73%, followed by "group activity" counting for 1.43%, and "teamwork" counting for 0.45%). The second frequent theme is "critical thinker" counting for 4.47% (in which the codes on "reflection" count for 3.54%, followed by "self-directed learning" counting for 1.25%). "Explorer" counts for 3.11% (in which the codes on "examine explain" count for 1.10%, "design build things" count for 1.05%, "research" count for 0.63%, and "explore and identify" count for 0.32%). The above data indicate that the role of the student in the curriculum from the UK focuses on “team worker.” The students learn mainly by sharing and reflecting on ideas in group activities.

5.2.6 Milieu

To address the sub-question of what the milieux of the selected AI curricula for K-12 are, I generated 65 codes on milieu. Figure 15 shows the coverage percentage of codes on the milieu I generated from data analysis.

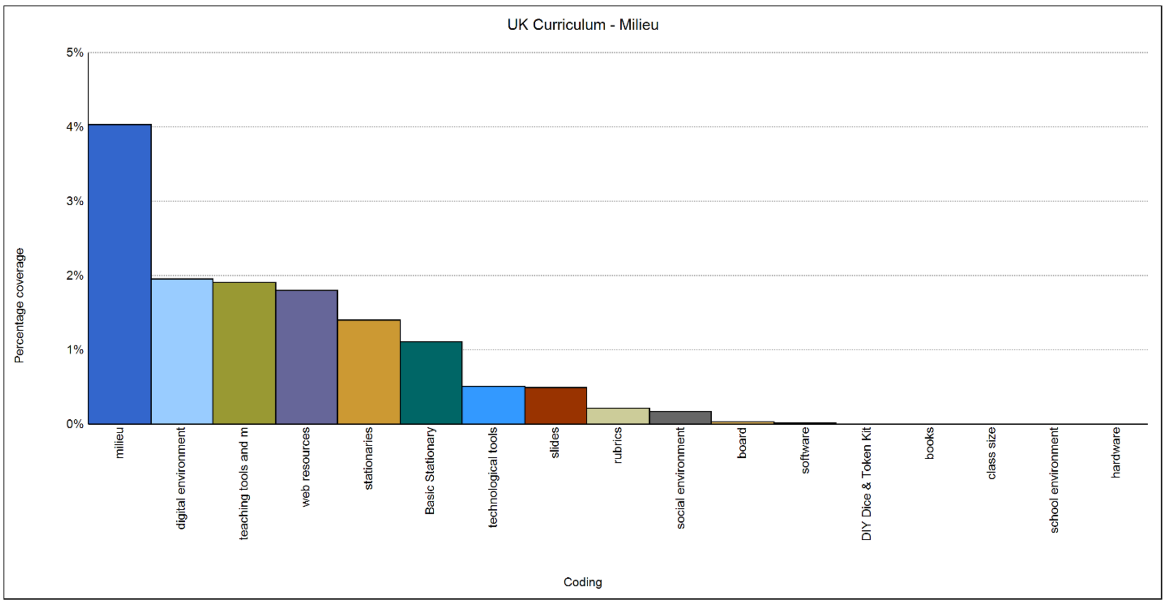

Figure 15: Coverage Percentage of Codes on Milieu of *Alternate Unit: Artificial Intelligence*

Milieu counts for 4.03% in coverage percentage. Four themes were generated on milieu of the curriculum from the UK from data analysis, namely, “social environment”, “school environment”, and “teaching tools and materials” and “digital environment.” The curriculum from the UK covers a wide range of themes and categories of “milieu” (see Figure 7 for the structure of themes and categories). Codes on “digital environment” (1.95%) become the most frequent group (in which the codes on “web sources” count for 1.80%). “Teaching tools and materials” comes as the second frequent theme counting for 1.91% (in which the codes on “stationery technical tools” count for 1.39% and “technical tools" count for 0.51%). The theme of "social environment" counts for 0.17%. "School environment" is not included in the curriculum from the UK.

The above data indicate that the milieu in the curriculum from the UK focuses on "digital environment" in which "web resources" serve as the major part of teaching materials and "stationaries" serve as major teaching tools. This is consistent with the design of mainly plugged activities of the curriculum from the UK.

5.3 « India*: CBSE Artificial Intelligence Curriculum* »

Different from the curricula from the US and the UK, the curriculum from India goes from the institutional level of curriculum to the programmatic level, and all the way down to the classroom level.

5.3.1 General information

As it is a curriculum created by the government, it covers more information on the institutional level. Before going to detailed classroom activities, the curriculum from India provides the readers a broad picture of AI education with lists and charts such as "Overview and Learning Objectives of the AI Program", "School Procedures for AI Implementation", "AI Implementation Procedures", "Suggestive Assessment Approaches for AI", "Interdisciplinary Integration with Artificial Intelligence", "AI Learning Indicators", and " AI Learning Outcomes" etc. The following table provides general information on the Indian AI curriculum.

Table 6: General Information on *CBSE Artificial Intelligence Curriculum*

Curriculum	CBSE Artificial Intelligence Curriculum
Created / supported by	Central Board of Secondary Education (CBSE) supported by Intel, India
Goals	Making students future ready and helping them work on incorporating Artificial Intelligence to improve their learning experience
Contents	1. Introduction to AI (Excite, Relate, Purpose, Possibilities, AI ethics) 2. AI project cycle (Problem scoping, Data acquisition, Data exploration, Modelling) 3. Neural network 4. Introduction to Python
Students	Grades 9th
Methods	Hands on – Activity based, Experiential learning, Inquiry based learning
Environment	Mainly unplugged

The curriculum from India is developed by the Central Board of Secondary Education (CBSE) for Grade 9 students as part of plans to cater to India's national AI Strategy that aims to effectively harness the potential of AI in a sustainable manner and to make India's next generation AI ready. This AI curriculum aims at "developing the learner's mindset and skills set towards artificial intelligence and how it is understood and applied" (p.5). Three dimensions of learning (Knowledge, Skills, Attitude) are stressed. Among the four selected curricula, the curriculum from India is the only curriculum that explicitly states its pedagogy as "Hands on – Activity Based, Experiential learning, Inquiry Based learning" (p. 6). Also, it is the only curriculum that includes 70 Hours of Python programming training in its content. Similar to the curriculum from the US, most of its activities are unplugged, although many online resources are included as part of the instruction.

5.3.2 Sample Activity/Lesson Plan

Unlike the curriculum from the UK which has a unified format and similar length for all the lesson plans, the curriculum from India features a variety in that the units and the sections in each unit vary in formats and duration. Therefore, I chose the "Excite" section in the first unit "Introduction to AI" as its duration is 2.4 hours, similar to the sample activity and lesson plan I have chosen from the curriculum from the US (about 3 hours) and the curriculum from the UK (165 minutes). Table 7 provides information on this sample activity in the curriculum from India.

Table 7: Sample Activity of *CBSE Artificial Intelligence Curriculum*

	General information	Examples quotes	Initial codes
Name	Excite		
Duration	2.4 hours		
Subject matter	Application of AI Three domains of AI	1. Describe application of AI in their daily lives. 2. Identify the 3 domains of AI.	AI application
Project /activity	Game	Students will play a few games that involve AI technology and computer applications.	games and competitions
Milieu	Materials Required, online Resources,	A4 Sheets, sketch-pens, AI Game Clues,	digital environment, slides,

		computers, headphones (With Microphone), Webcams, three different colored stands of thread	basic stationery, computer
Teaching process	1. Introduction to AI	Introduce the program to students. Ask the students to answer the questions that follow. Let them write their own views without any guidelines or instructions. After filling the questionnaire, discuss the answers with the whole class so that you get to know what their expectations are regarding the AI curriculum.	ask and prompt thinking, show, know students, discussion, sharing ideas, self-directed learning
	2. Dream Smart Home	We want to get to know you better. Design a layout of a floor plan of your dream smart home.	know student, design build things
	3. Activity – Game Time	Write down three rules in the given spaces you would set before playing any games? Game Descriptions: Rock, Paper & Scissors: A game based on Data for AI. Mystery Animal: A game based on Natural Language Processing. Emoji Scavenger Hunt: A game based on Computer Vision	explore and identify. data mining, natural language processing, image speech recognition
	4. Quiz Time: AI Quiz	The following are questions for the quiz. You can either go for a Pen/Paper Quiz or you can visit any open-sourced, free, online portal; one of which is Kahoot, and create your quiz there.	digital environments, basic stationery, ways of assessment
	5. Activity: Letter to Future Self	I would like you to put on your reflective cap and write a letter to your future self. What do you want to tell yourself or remind yourself?	reflection, organize activities, ask and prompt thinking

As shown in Table 7, the curriculum from India covers the subject matter of “application of AI” and “domains of AI” in the first unit. The Facilitator Guide summarizes the objectives and expected learning outcomes of this section. Besides learning AI knowledge, the objectives also include “solving problems by practicing critical thinking and self-directed learning” (p. 15). The teacher in the curriculum from India starts the lesson by introducing the objectives of the program and asking questions about students’ knowledge of AI in order to know the students. Then the teacher explains what AI is. In NVivo coding, the teacher’s action is labeled as “ask and prompt thinking”, “show”, “know students” in the category of “role of teacher”, while the students’ action is labeled as “discussion”, “sharing ideas”, and “self-directed learning” in the category of “role of student.” In the second step, the teacher in the curriculum from India organizes an activity entitled “Dream Smart Home” by asking questions to prompt thinking about AI application with the aim of better knowing the students. In NVivo coding, I label these teacher’s actions as “know students”, and students’ actions as “design build things.” In the third step, the students in the curriculum from India play three games to explore the three domains of AI. This is labeled as “explore and identify.” The three domains are labeled in the category of “subject matter.” In the fourth step, the students take a paper quiz or an online quiz. “Digital environments” and “basic stationery” are labeled in the category of “Milieu.” The curriculum from India is the only curriculum among the four selected curricula that has written quizzes for each section and this is labeled as “ways of assessment.” In the fifth step, the students in the curriculum from India write a letter to the future self to recap the thoughts from this class. Codes like “organize activities” and “ask and prompt thinking” are added to the “role of teacher” category, and “reflection” to the “role of student” category.

In the following part, the numeric data that are generated from the NVivo coding are presented within the analytical framework of Schwab’s (1969) four commonplaces of curriculum: the teacher, the student, the subject matter, and the social milieu.

5.3.3 Subject Matter

To address the sub-question of what subject matters are included in the selected AI curricula, the subject matters of the Indian AI curriculum are analyzed and presented in this part. I generated 170 codes in the 126 pages curriculum from India using NVivo 12 Pro.

Figure 16 shows the coverage percentage of codes on the subject matter of the curriculum from India.

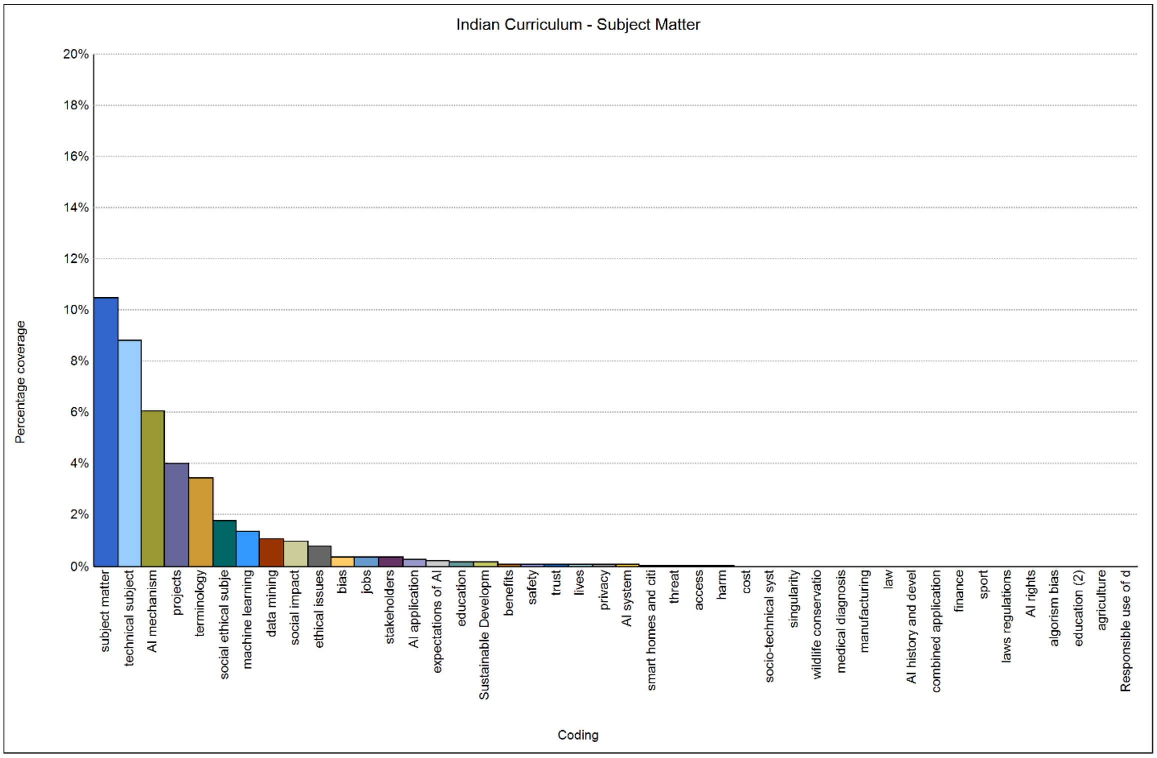

Figure 16: Coverage Percentage of Codes on Subject Matter of *CBSE Artificial Intelligence Curriculum*

"Subject Matter" counts for 10.50% in the curriculum from India. Its two themes, "Social ethical subject" counts for 1.80% and "technical subject" counts for 8.83%. Under "Social ethical subject", "social impact" counts for 1.00%, and "ethical issues" counts for 0.79%. In the subcategory of "technical subject", "AI mechanism" counts 6.08%, making it the most frequent coding category. "Projects", counting for 4.06%, comes second. The third largest theme is "terminology" (3.46%). "AI application" (0.27%) comes last. "AI history and development" is not included in the curriculum from India. The above data indicate that the curriculum from India covers a wide range of subject matters in its content with an emphasis on technical subject matter.

A detailed illustration of the contents of the subcategory of "ethical issues" and "social impact" shows that under the umbrella of "ethical issues", the curriculum from India covers quite a few subjects, such as "bias" (which covers "social ethical system", and "stakeholders"), "safety"(which covers the issue of "trust") "benefits", "privacy", “access”, “threat”, “harm”, and “cost” (see Figure 3 for the structure of categories). Codes on “bias” count 0.39% in coverage percentage, becoming the most frequently mentioned subject in the category of “ethical issues” (in which the codes on “stakeholders” alone count for 0.36%, followed by “social technical system” counting for 0.01%, and “algorithm bias” is not covered). In the category of “social impact”, “jobs”, which counts for 0.38%, tops the list, followed by “expectations of AI” (0.22%) (in which “sustainable development goals” counts for 0.19%), “education” (0.21%), and “lives” (0.08%). The above data indicate that the curriculum from India focuses on “bias” and “jobs” as the subject matter.

A detailed illustration of the contents of the subcategory of “technical subject” shows that the curriculum from India covers a wide range of subjects in the category of “technical subject”, such as “AI mechanism” (which covers “machine learning”, “data mining”, “projects”, “AI system”), “terminology”, “AI application” (which covers “smart home and schools”) (see Figure 4 for structure of themes and categories). Codes on “AI mechanism” (6.08%) top the subcategories in “technical subject” (in which the codes on “projects” alone count for 4.06%, followed by “machine learning” counting for 1.36%, “data mining” counting for 1.09%, and “AI system” counting for 0.07%). In the category of “AI application” (0.27%), only one type of code is generated, namely “smart home and schools” (0.05%). “Terminology” counts for 3.46%, which covers a wide range of terms such as “artificial intelligence”, “deep learning”, “clustering”, “classification”, “neural network”, “regression model”, “layer”, “algorithm”, “machine learning” and “AI modelling” on the list. The above data indicate that the curriculum from India is a well-balanced curriculum in terms of subject matter. However, it gives great emphasis on technical aspects and covers limited information on AI applications.

5.3.4 Role of Teacher

To address the sub-question of what the roles of the teachers of the selected AI curricula for K-12 are, I generated 190 codes in the curriculum from India on role of teacher. Figure 17 shows the coverage percentage of codes on the role of teacher I generated from data analysis.

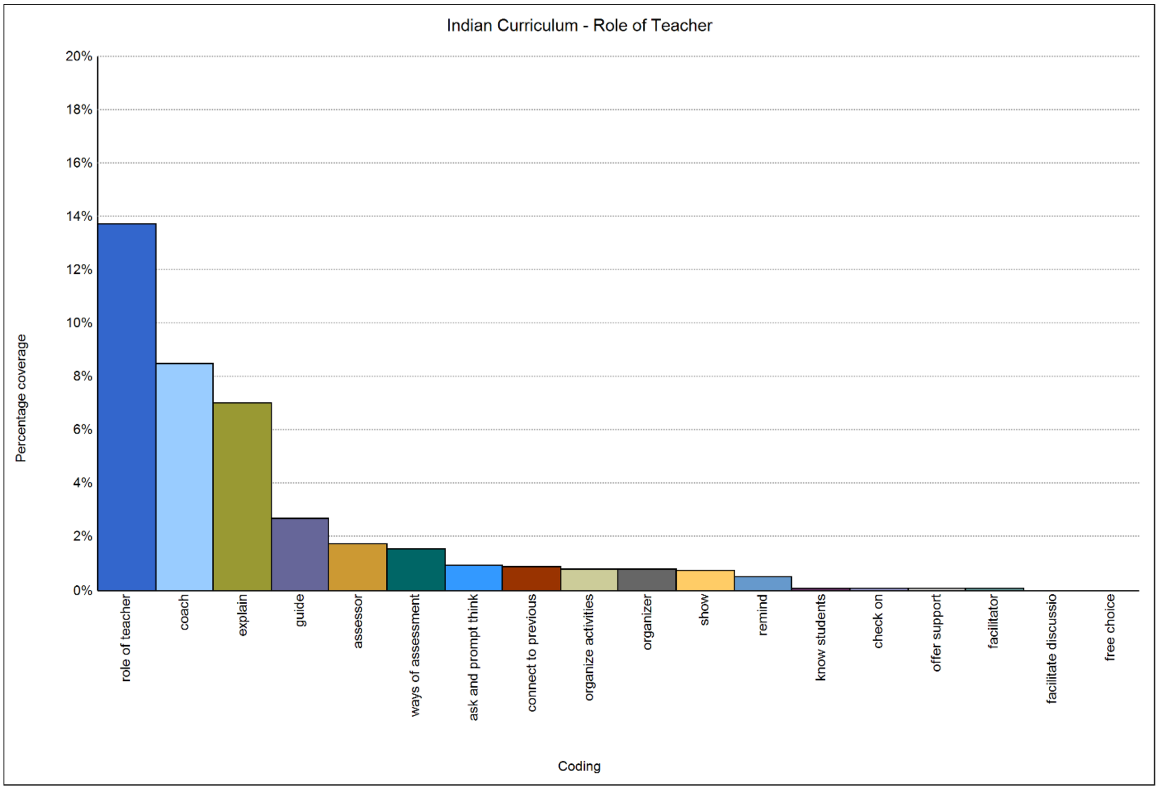

Figure 17: Coverage Percentage of Codes on Role of Teacher of *CBSE Artificial Intelligence Curriculum*

"Role of teacher" counts for 13.73% in coverage percentage. I generated 5 themes from data analysis, namely, "guide", "coach", "facilitator", "organizer", and "assessor". The curriculum from India covers a wide range of themes and categories on "role of teacher" (see Figure 5 for the structure of themes and categories). Codes on "coach" (8.49%) top the themes in "role of teacher" (in which the codes on "explain" alone count for 7.03%, followed by "connect to previous lesson" counting for 0.90%, and "show" counting for 0.76%. "Guide" (2.71%) comes second (in which the codes on "ask and prompt thinking" count for 0.97%, followed by "remind" counting for 0.53%, "check on" counting for 0.09%). Following are the theme of "assessor" which counts for 1.74%, the theme of "organizer" which counts for 0.83%, and the theme of "facilitator" which counts for 0.08%.

The above data indicate that the role of teacher in the curriculum from India focuses on "coach" and "guide" and the teacher teaches mainly by explaining and guiding students to learn. However, it covers limited information on the teacher's role as "facilitator".

5.3.5 Role of Student

To address the sub-question of what the roles of the students of the selected AI curricula for K-12 are, I generated 182 codes in the curriculum from India on the role of student. Figure 36 shows the coverage percentage of codes on the role of student I generated from data analysis.

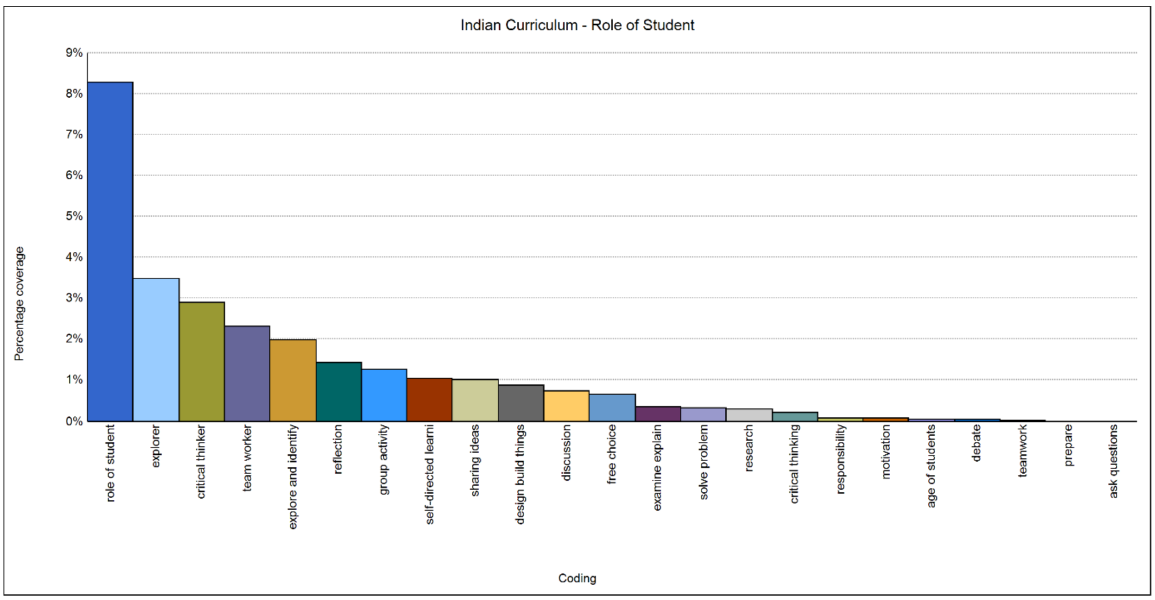

Figure 18: Coverage Percentage of Codes on Role of Student of *CBSE Artificial Intelligence Curriculum*

"Role of student" counts for 8.29% in coverage percentage. Three themes are generated from data analysis, namely, "explorer", "team worker", and "critical thinker". The curriculum from India covers a wide range of themes and categories of "role of student" (see Figure 6 for the structure of themes and categories). Codes on "explorer" (3.48%) top the themes in "role of student" (in which the codes on "explore and identify" count for 1.99%, followed by "design build things" counting for 0.89%, "examine explain" counting for 0.37%, "research" counting for 0.31%). The second frequent theme is "critical thinker" counting for 2.91% (in which the codes on "reflection" count for 1.44%, followed by "self-directed learning" counting for 1.05%, "solve problems" counting for 0.35%, and "critical thinking" counting for 0.23%). The above data indicate that the roles of student in the curriculum from India are evenly distributed. The major way for students to learn is to explore and identify.

5.3.6 Milieu

To address the sub-question of what the milieux of the selected AI curricula for K-12 are, I generated 79 codes in the curriculum from India on milieu. Figure 19 shows the structure of coverage percentage of codes on milieu I generated from data analysis.

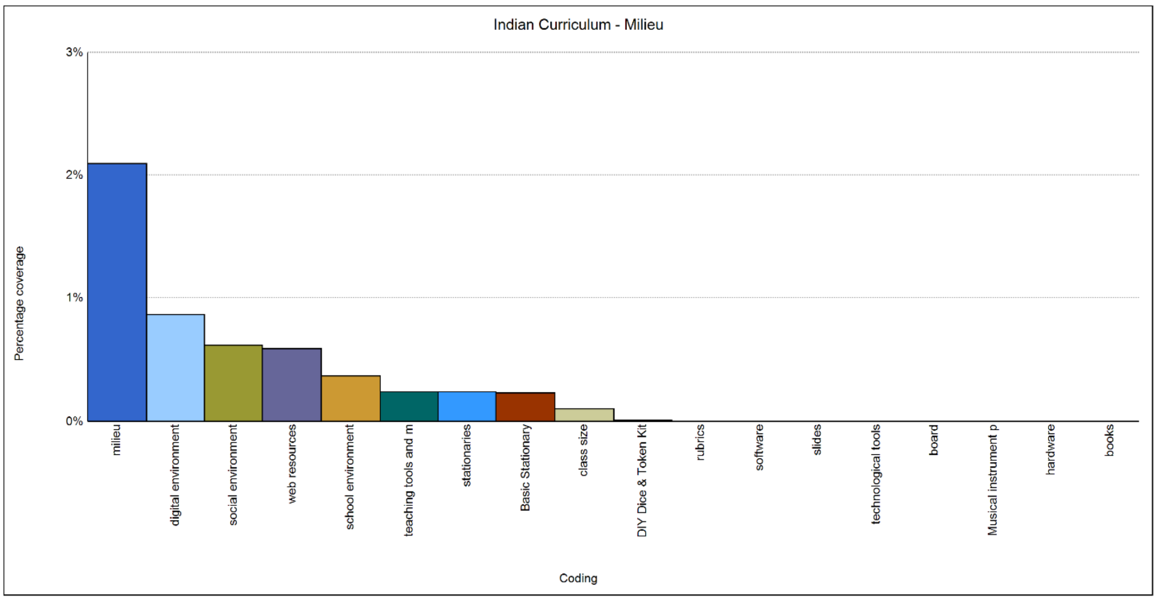

Figure 19: Coverage Percentage of Codes on Milieu of *CBSE Artificial Intelligence Curriculum*

Codes on milieu count for 2.09% in coverage percentage in the curriculum from India. Four themes are generated from data analysis, namely, "social environment", "school environment", and "teaching tools and materials" and "digital environment." The curriculum from India covers a wide range of themes and categories of "milieu" (see Figure 7 for the structure of themes and categories). Codes on "digital environment" (0.86%) become the most frequent group (in which the codes on "web sources" count for

0.59%). The second frequent theme is “social environment” which counts for 0.62%. The theme of “school environment” and “teaching tools and materials” count for 0.37% and 0.24% respectively. In the category of “school environment”, “classroom size” (0.10%) is emphasized in each activity. The above data indicate that the milieu in the curriculum from India focuses on “digital environment” in which “web resources” serve as the major part of teaching materials and “social environment” serves as the teaching context in which activities and subject matters are set. This is consistent with the design of mainly plugged activities of the curriculum from India.

5.4 « Canada: *Actua’s AI Education Handbook* »

Of the four selected curricula for study, the curriculum from Canada is of a different kind in terms of curriculum levels discussed in chapter one. Different to the other three selected curricula which all cover the programmatic curriculum and classroom levels of curriculum (the curriculum from India also includes the institutional level of curriculum), the curriculum from Canada remains on the institutional and programmatic levels. As its target group is educators instead of students, it does not go to the classroom level.

5.4.1 General information

The following table provides general information on the curriculum from Canada.

Table 8: General Information on *Actua’s AI Education Handbook*

Curriculum	Actua’s AI Education Handbook
Created/supported by	Google.org and CIRA, Canada
Goals	Support educators with background information on AI, a curriculum-aligned framework, and ideas for classroom implementation.
Contents	I. Artificial Intelligence: A Primer for Educators 1.Why AI (A brief history, Narrow vs. general intelligence) 2.Application of AI (Recognition, Conversational, Predictive analytics, Personalization, Autonomous vehicles / systems, Anomaly detection & pattern recognition, Goal-driven systems, Combined applications) 3.AI technologies (Machine learning, Deep learning, Other areas of AI: Natural language processing & computer vision, Precision, Recall and error recovery) II. Actua’s AI for Education Framework III. Bringing AI into the K-12 Classroom IV. Glossary
learners	Educators
Methods	Not stated

Environment	Both with technology and in unplugged environments

The major goal of the curriculum from Canada is to "support educators with background information on AI, a curriculum-aligned framework, and ideas for classroom implementation" (p. 4). There are four main parts of the curriculum from Canada. First, the "AI Primer" section is intended to "provide teachers with a brief overview of the fundamental concepts and content needed to understand AI before bringing it into classroom instruction" (p. 5). The first half of the primer presents AI through an applications lens to introduce the range of use cases for AI technologies. The second half of the primer introduces some of the underlying technologies that make up the AI landscape and help break down complex jargon and terminology. Second, "AI for Education Framework" explains how to structure the approach to AI education for K-12 classrooms. This framework provides relevant, actionable steps for implementing AI activities with students. Third, "Bringing AI into the K-12 Classroom" provides ideas for hands-on ways to make AI come alive for students, followed by Actua's recommendations for additional resources. This curriculum is designed to "accompany Actua's workshop series for educators which provide hands-on opportunities to explore AI concepts in action, both with technology and in unplugged environments" (p. 4). The last section provides glossary.

Sample Activity/Lesson Plan

One important feature of the curriculum from Canada is that it does not go to the classroom curriculum level, so it does not include individual activities in the curriculum itself. Instead, the curriculum from Canada provides a link to the activity website (actua.ca/en/activities) that includes some, and increasingly more, interdisciplinary, hands-on activities for different age groups of students to explore AI concepts based on Actua's AI Education framework. "Each activity will have a recommended progression for educators who would like to work with students on AI through a multitude of lenses" or "smaller-scale AI explorations can be undertaken by using single activities, each of which is designed to take 1-3 hours, in order to investigate a single AI concept" (p. 26). Among the four available Actua activity documents, only one is targeted at 9-10 grade students. Therefore, I choose "Classifying Text with Machine Learning" as the sample plug-in activity for this curriculum. Table 9 provides information on this sample activity in the curriculum from Canada.

Table 9: Sample Plug-In Activity of *Actua's AI Education Handbook*

	General information	Examples quotes	Initial codes
Name	Classifying Text with Machine Learning	Classifying Text with Machine Learning	machine learning,
Target group	Grade 9		
Duration	60 minutes		
Subject matter	Classification Machine learning	Using Machine Learning for Kids, participants will have the opportunity to add data and begin training your machine. The whole activity can be adapted with different text classification options.	Machine Learning, classification
Project /activity	Add data and begin training your machine.	Participants will have the opportunity to add data and begin training your machine.	data, design build things
Milieu	One computer for each team of 4 Python	Materials 1 computer for each team of 4. You can follow the instructions which can be downloaded from here to set up your free Lite account on the IBM Cloud. Printed out or written out the five sets of four keywords	digital, environment computer, basic stationery
Activity Procedure	1.To Do in Advance	Create some accounts so that you can access all the required resources.	digital environment, web resources
	2. Opening Hook: Understanding Meaning in Voice	We will begin by recapping the information given in step one to the participants, before explaining that once participants see the four words, they will have two minutes to sketch out what they think the photo is going to be. Once two minutes are up, give the group some time to share their sketches with each other and have some laughs. Following this, ask some of the participants why they chose to draw what they did. Next, show the actual image to the class, once participants have had thirty seconds to think about it- begin a conversation on why they believe the words correspond to the image, and if they would have made a different choice then Google Repeat this process for any number of keywords and photos, it is encouraged to create your own setup of cards to suit your	Connection to previous lesson, Explain, Sharing ideas, ask and prompt thinking, show, free choice

		own group, but an example set can be found here.	
	3. Reflection & Debrief	Ask the participants about how this changes the way they look at computers? How does this process benefit us and is there a better way we could interpret text with an AI? Have the participants turn to an elbow buddy and talk for 30 seconds about what they would do differently if given another chance.	ask and prompt thinking, sharing ideas
	4. Extensions & Modifications	How might you adapt the time, space, materials, group sizes, or instructions to make this activity more approachable or more challenging?	free choice

As shown in Table 9, the curriculum from Canada has a plug-in activity on the subject matter of "Classifying Text with Machine Learning." The "Activity Summary" section summarizes the objectives and precautions of this activity. In the "Activity Procedure" section, the teacher in the curriculum from Canada starts with "To Do in Advance" by creating the free Lite account on the IBM Cloud for student activity. In NVivo coding, the teacher's action is labeled as setting up the "digital environment" in the category of "milieu." In the second step "Opening Hook", the teacher's role is labeled as "connection to previous lesson", "explain", "ask and prompt thinking", "show", "free choice" and the students' role is labeled as "sharing ideas". In the third step, the teacher leads the students to reflect upon the activity by asking questions. This is labeled as "ask and prompt thinking" and the students share ideas in discussion. The fourth step is unique in that it offers the teacher the freedom to "adapt the time, space, materials, group sizes, or instructions to make this activity more approachable or more challenging" with extensions or/and modifications (n.p.). In NVivo coding, it is labeled as "free choice" in the category of "role of teacher."

5.4.2 Subject Matter

To address the sub-question of what subject matters are included in the selected AI curricula for K-12, the subject matters of the AI curriculum from Canada are analyzed and presented in this part. I generated 131 codes in the 37 pages curriculum from Canada using NVivo 12 Pro. Figure 20 shows the coverage percentage of codes on the subject matter of the AI curriculum from Canada.

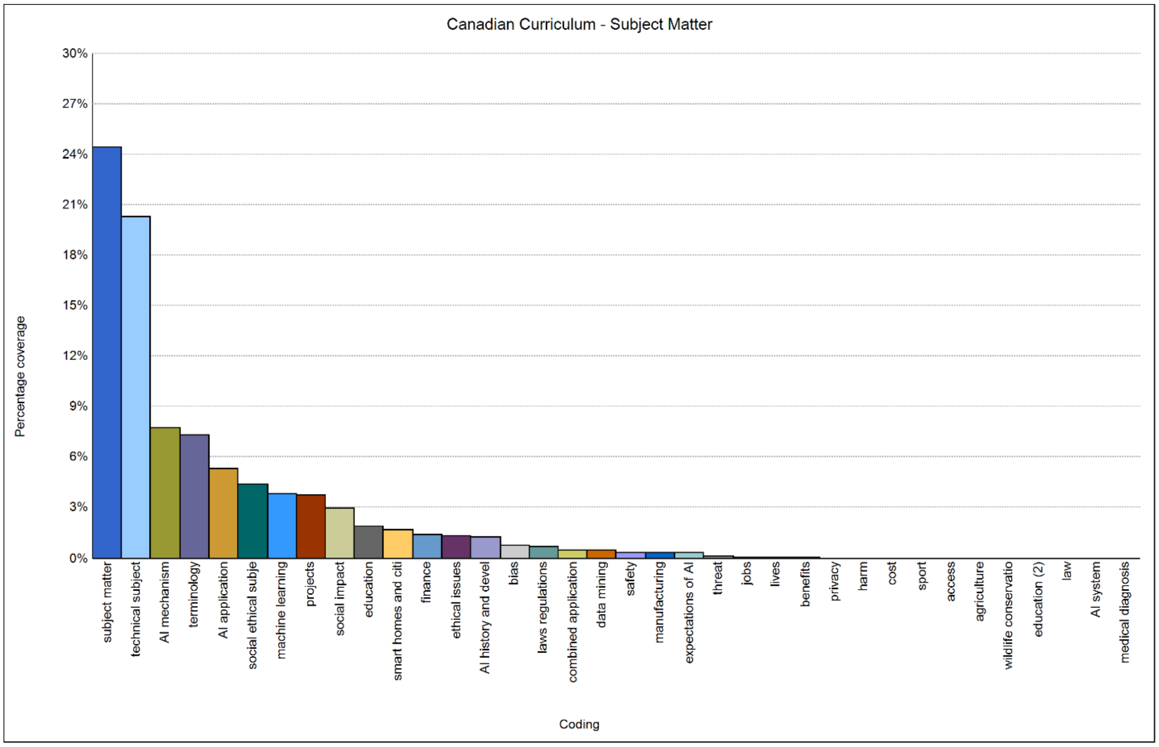

Figure 20: Coverage Percentage of Codes on Subject Matter of *Actua's AI Education Handbook*

"Subject Matter" counts for 24.44% in the curriculum from Canada, the highest proportion among the four selected curricula. Its two categories, "technical subject" and "Social ethical subject" count for 20.34% and 4,41% respectively. In the subcategory of "technical subject", "AI mechanism" counts for 7.80%, making it the most frequently coded subcategory. "Terminology" (7.36%) follows. The third largest theme is "AI application" (5.36%). "AI history and development" comes last, counting for 1.26% in coverage percentage. Under "Social ethical subject", "social impact" counts for 3.03% (in which "education" alone counts for 1.92%), and "ethical issues" counts for 1.37%. The above data indicate that the curriculum from Canada covers a wide range of subject matters in its content with an evident emphasis on technical subject matters.

A detailed illustration of the contents of the subcategory of "ethical issues" and "social impact" shows that under the umbrella of "ethical issues", the curriculum from Canada covers quite a few subjects, such as "bias" (which covers "stakeholders"), "safety", "threat", and "benefits" (see Figure 3 for the structure of categories). Codes on "bias" count 0.78% in coverage percentage, becoming the most frequently mentioned subject in the category of “ethical issues” (in which the codes on “stakeholders” alone count for 0.44%, “social technical system” and “algorithm bias” are not covered). In the category of “social impact”, “education” counting for 1.92%, tops the list, followed by “laws and regulation”, counting for 0.68%, “expectations of AI” (0.32%) (in which “sustainable development goals” counts for 0.19%), “laws and regulations” (0.73%), “jobs” (0.11%), “lives” (0.09%). The above data indicate that the curriculum from Canada puts emphasis on “education” as the subject matter in the category of “social ethical subjects.”

A detailed illustration of the contents of the category of “technical subject” shows that in the category of “technical subject”, the curriculum from Canada covers a wide range of subjects, such as “AI mechanism” (which covers “machine learning”, “data mining”, “projects”, “AI system”) “terminology”, “AI application” (which covers “smart home and schools”, “finance”, “combined application” and “manufacturing”) (see Figure 4 for the structure of themes and categories). Codes on “AI mechanism” (7.08%) top the subcategories in “technical subject” (in which the codes on “machine learning”, counting for 3.83%, followed by “projects”, counting for 3.77%, “data mining”, counting for 0.49%, and “AI system” is not included in the curriculum from Canada). “Terminology” counts for 7.36%, which covers the widest range of terms such as “artificial intelligence”, “machine learning”, “confusion matrix”, “deep learning”, “clustering”, “classification”, “neural network”, “regression model”, “label”, “natural language understanding”, “feature”, “layer”, “sentiment analysis”, “classification”, “reinforcement learning”, “association”, “interpretability”, “anomaly detection”, “recall”, “precision”, “neural network”, “regression model”, “clustering”, “computer vision”, “predictive analysis”, “deep model”, “algorithm”, “label or target”, and “feature” on the list, making the longest list among the four selected curricula. In the category of “AI application” (5.36%), “smart home and schools” counts for 1.72%, followed by “finance” (1.45%), combined application (0.49%), and “manufacturing” (0.33%). The above data indicate that the curriculum from Canada focuses on technical subject matters and covers a lot of information on terminologies. At the same time education is stressed in the curriculum from Canada. This is consistent with the purpose of the curriculum which reflects the national strategy of Canada aiming to develop AI research and cultivate top AI talent.

5.4.3 Role of Teacher

As the curriculum from Canada does not go to the classroom curriculum level, it is more meaningful to study the activities provided on its activity website in terms of the role of teacher and the role of student. Figure 21 shows the coverage percentage of codes on role of teacher I generated from data analysis on the class activity document of the curriculum from Canada instead of the curriculum itself. I generated 17 codes in the activity document on role of the teacher.

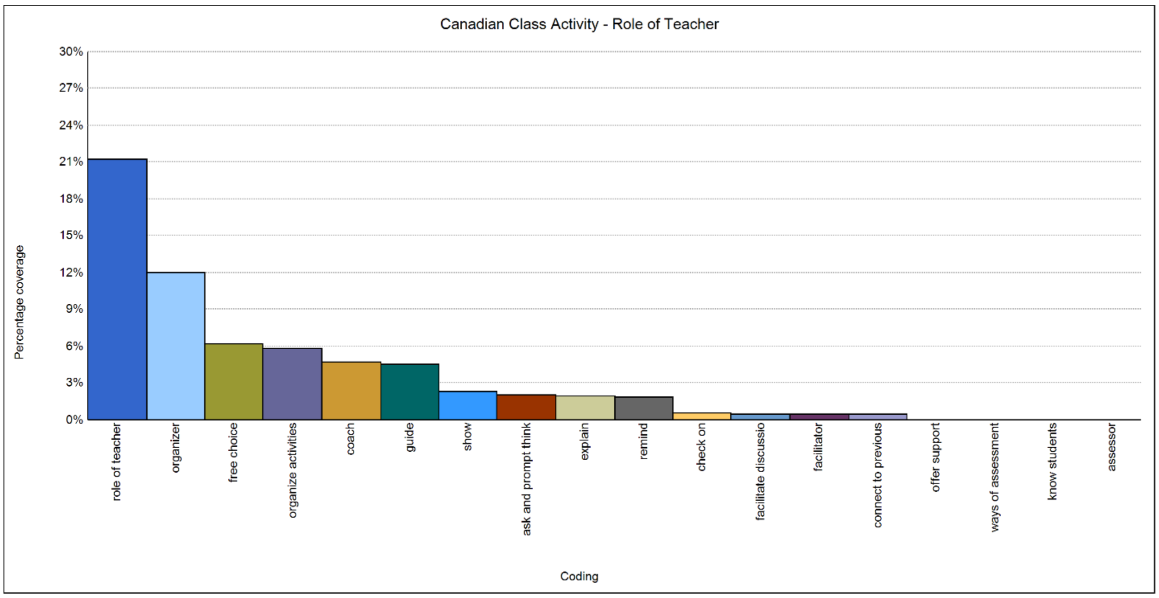

Figure 21: Coverage Percentage of Codes on Role of Teacher of *Actua's* Activity Document

Figure 21 shows the coverage percentage of codes on the role of teacher. "Role of teacher" counts for 21.20% in coverage percentage. Four themes from thematic analysis are generated, namely "guide", "coach", "facilitator", "organizer." The class activity of the curriculum from Canada is the only one that does not cover the theme of "assessor" in categories of "role of teacher" (see Figure 5 for the structure of themes and categories). Codes on the theme of "organizer" top the list with 11.99% of coverage percentage in which "free choice" counts for 6.22%, giving the greatest flexibility for the teacher to choose the subject matter to adapt to their students. Codes on "organizing activities" count for 5.77% in the category of the theme of "organizer." "Coach" (4.74%) comes as the second frequent theme in “role of teacher” (in which the codes on “show” count for 2.35%, followed by “explain”, counting for 1.93%, and “connect to previous lesson” counting for 0.45%). “Guide” (2.71%) comes third (in which the codes on “ask and prompt thinking” count for 2.04%, followed by “remind”, counting for 1.85%, “check on”, counting for 0.60%). The last is the theme of “facilitator” which counts for 0.49%.

The above data indicate that the role of teacher in the class activity document of the curriculum from Canada focuses on “organizer” and the teacher teaches mainly by organizing class activities. However, it covers no information on the teacher’s role as “assessor.” One important feature of the roles of a teacher in the curriculum from Canada is that the greatest freedom is allotted to the teacher to decide what and how to teach to a certain class with a certain learning background.

5.4.4 Role of Student

Similarly, as the curriculum from Canada does not go to the classroom curriculum level, the role of student is studied on the activities provided on its activity website. Figure 22 shows the coverage percentage of codes on the role of student generated from data analysis. I generated 12 codes in the activity curriculum on the role of student.

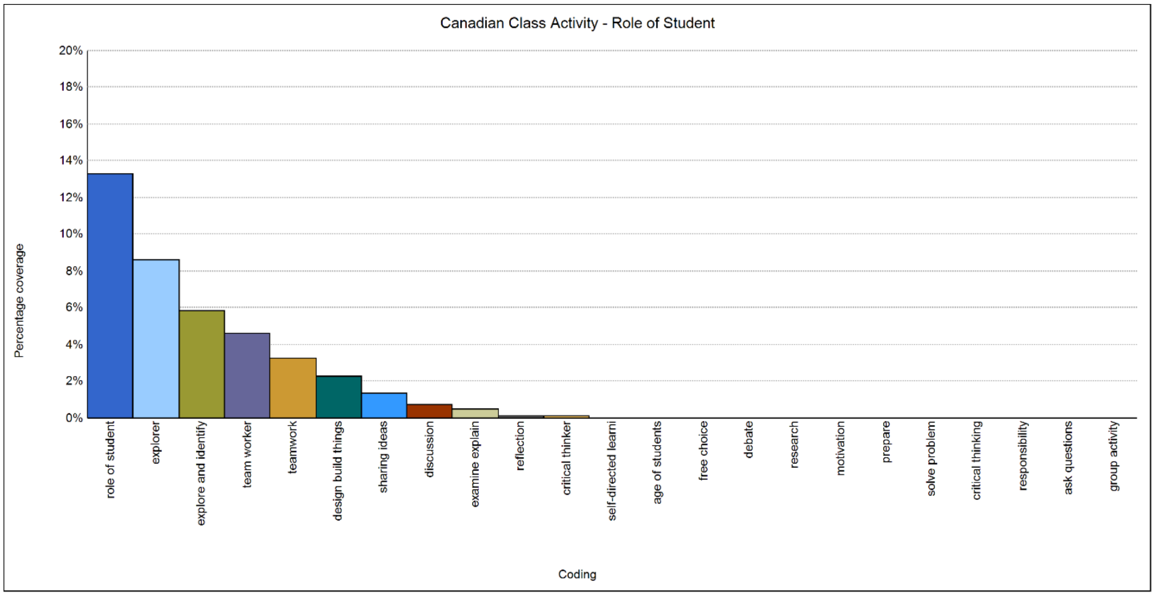

Figure 22: Coverage Percentage of Codes on Role of Student of *Actua's* Activity Document

"Role of student" counts for 13.32% in coverage percentage. Three themes were generated from thematic analysis, namely, "explorer", "team worker", and "critical thinker". The class activity document of the curriculum from Canada covers a wide range of themes and categories of "role of student" (see Figure 6 for the structure of themes and categories). Codes on "explorer" (8.61%) top the themes in "role of student" (in which the codes on "explore and identify" count for 5.83%, followed by "design build things" counting for 2.29%, "examine explain" counting for 0.50%, "research" is not included). The second frequent theme is "team worker" counting for 4.60%, (in which "teamwork" counts for 3.25%, "sharing ideas" counts for 1.35% "group activity" is not included). "Critical thinker" counts for 0.11% (in which "reflection" is the only subcategory). The above data indicate that the roles of a student in the class activity of the curriculum from Canada are not evenly distributed. The major way for students to learn is to explore and identify. Information on critical thinking is limited.

5.4.5 Milieu

To address the sub-question of what the milieux of the selected AI curricula for K-12 are, I generated 50 codes in the curriculum from Canada on milieu. Figure 23 shows the coverage percentage of codes on the milieu I generated from data analysis.

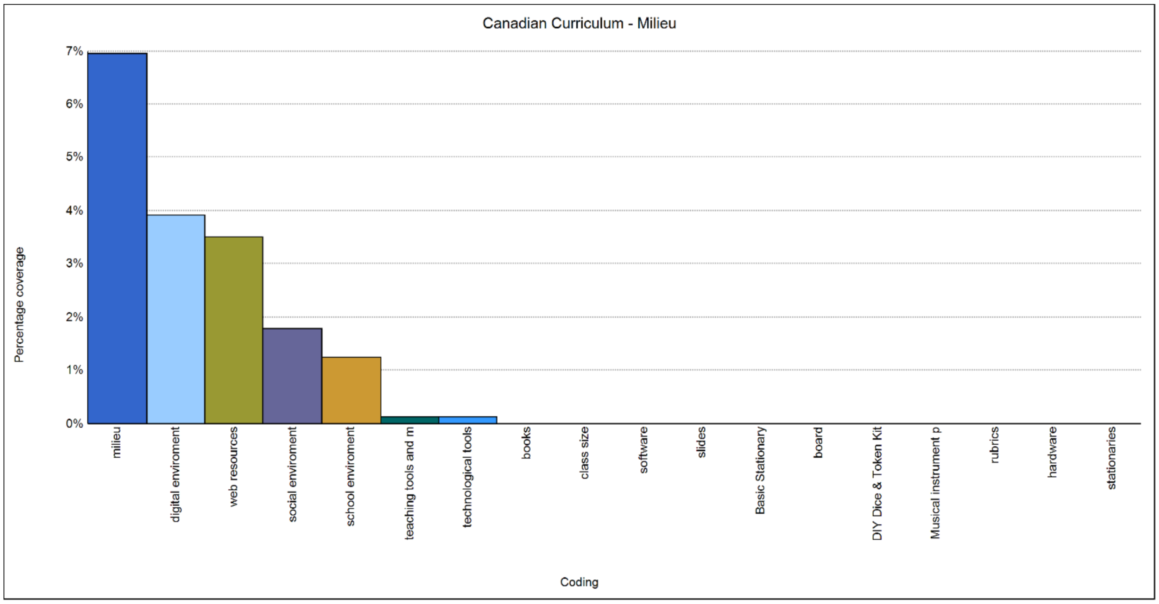

Figure 23: Coverage Percentage of Codes on Milieu of *Actua's AI Education Handbook*

Figure 23 shows the coverage percentage of codes on milieu. The coverage percentage of "Milieu" is 6.96%. Four themes are generated from thematic analysis, namely, "social environment", "school environment", and "teaching tools and materials" and "digital environment." The curriculum from Canada covers a wide range of themes and categories of "milieu" (see Figure 7 for the structure of themes and categories). Codes on "digital environment" (3.93%) become the most frequent group (in which the codes on "web sources" count for 3.51%). The second frequent theme is "social environment" which counts for 1.79%. The theme of "school environment" and "teaching tools and materials" count for 1.24% and 0.13% respectively. The above data indicate that the milieu in the curriculum from Canada focuses on "digital environment" in which "web resources" serve as the major part of teaching materials and "social environment" serves as the teaching context in which activities and subject matters are set. As this curriculum is on the institutional and programmatic levels, the teachers are left with great flexibility to decide the teaching tools to suit the contents.

Chapter 6

6 « Discussion »

The second research question is “How do the four selected AI curricula for K-12 converge and diverge in their features of pedagogical approaches?” As mentioned in Chapter 1, Murphy’s (2009) definition of pedagogy stresses the “interactions between teachers, students and the learning environment and the learning tasks” (p. 35). To Address this research question, a cross-curricula analysis is conducted through further discussion of the first research question and its four sub-questions from a comparative perspective. This chapter will unearth the similarities and differences of each curricular commonplace among the selected AI curricula and investigate the pedagogical approaches of the four selected AI curricula for K-12 through the lens of (socio) constructivism and constructionism learning theories. As mentioned in Chapter 4, Schwab’s theory (1969) of four commonplaces is used to magnify the importance of each of the commonplaces as while as to emphasize the necessity for cohesion among them. To create a curriculum that allows for the meaningful translation of content, the relationship between each of the four commonplaces within a curriculum needs to be considered. In this chapter, the subject matters, the roles of teachers, the roles of students, and the milieux of these selected AI curricula are comparatively analyzed individually and then discussed as a whole to study the pedagogical approaches involved in the four selected curricula. In order to present a cross-curricula analysis in this chapter, I use tables to point out the similarities and differences among the curricula, discussing the findings presented in Chapter 5, and connecting the findings to the theoretical framework and the literature.

6.1 « Subject Matter of the Selected AI Curricula »

In order to discuss the “learning tasks” (Murphy, 2009, p. 35) of the selected AI curricula, the subject matters of these curricula are analyzed comparatively. The subject matter to be taught is an indispensable component of curriculum design. It is “the source from which and by which selection is made of the provocative objects and events which serve as catalysts of curricular activity” (Schwab, 1973, p. 509). Without subject matter to be taught, teaching could not simply exist. Important as it is, subject matter coexists with the teacher, the student, and the milieu. The analysis on subject matter makes sense only when it is connected with the other commonplaces.

6.1.1 Comparison on Subject Matter of Selected Curricula

Table 10 shows the number of codes on subject matter of the four selected curricula.

Table 10: Number of Codes on Subject Matter

	Curriculum from Canada	Curriculum from India	Curriculum from the US	Curriculum from the UK
Subject matter	131	170	93	228
Social ethical subject	23	47	50	116
Ethical issues	8	18	46	61
Social impact	16	28	4	54
Technical subject	111	125	46	118
AI application	28	14	3	36
AI history and development	4	0	0	5
AI mechanism	42	85	34	64
Terminology	48	38	9	16

I generate 131codes on the curriculum from Canada, 170 codes on curriculum from India, 93 codes on the curriculum from the US, 228 codes on the curriculum from the UK for subject matter. As the curricula have different lengths and there are overlaps of the same codes in different categories, these numbers are meaningful only in comparison. The two themes in subject matter, “social ethical subject” and “technical subject” (highlighted with a light green background), vary in their relative weights in different curricula. As shown in Table 3, the curricula from Canada and India both have much more codes on technical subjects than on social ethical subjects (111:23 and 125:47). The curriculum from the UK has a similar number of codes on technical subjects and social ethical subjects (118:116). However, the curriculum from the US is the only one that has more codes on social and ethical subjects than on technical subjects (50:46). The curriculum from Canada includes the largest proportion of terminologies while the curriculum from India includes the most information on AI mechanism. The curriculum from the US has the largest proportion of codes on ethnical subjects, as almost half of the codes in the curriculum from the US are on ethical subjects. Among the four curricula selected for this study, the curriculum from the UK is the most balanced and inclusive curriculum in terms of subject matters. The curricula from Canada and India are similar in that both put emphasis on the technical aspects in their choice of subject matters. The curriculum form the US focuses on social and ethical subject matters but provides limited information on AI application in its content.

6.1.2 Why the Differences

The different weights on themes of subject matters are consistent with different objectives of the curricula. The major goal of the curriculum from Canada is to “support educators with background information on AI, a curriculum-aligned framework, and ideas for classroom implementation” (p. 4). The curriculum from India aims to “effectively harness the potential of AI in a sustainable manner and to make India’s next generation AI ready” by “developing the learner’s mind set and skills set towards artificial intelligence and how it is understood and applied” (p. 5). As a result, these two curricula are more on the technical side to provide AI knowledge on AI mechanisms and AI applications to the learners. The AI curriculum from the UK aims to “demystify the topic of AI” in a broad sense, “with students gaining an understanding of terminology such as machine learning, deep learning, and other AI-associated terminology. Students will gain knowledge and skills while considering the social, moral, and ethical impacts of AI systems and usage” (p. 3). To this end, the curriculum from the UK balances the two aspects of subject matters. With a focus on the ethics of AI, the curriculum from the US aims to teach students “basic mechanics of artificial intelligence systems” with an understanding that “all technical systems are socio-technical systems” that can “affect many stakeholders differentially” (pp. 7-8). Thus, the curriculum from the US put more emphasis on the social and ethical aspects of subject matter and focuses on “ethical issues.” For technical subjects, three curricula except the curriculum from Canada focus on “AI mechanism.” The curriculum from Canada emphasizes more on “terminologies.” In all these curricula, “AI history and development” is the least mentioned subject. In fact, it is not included in the curriculum from the US or the curriculum from India.

6.1.3 Why K-12?

Although AI is a subject familiar at the graduate level in higher education, students still find the scope and complexity of AI to be "quite daunting and incomprehensible" (Wong, Ma, Dillenbourg & Huan, 2020, p. 24). One might wonder how could complicated ideas about AI which are usually a subject of computer science in higher education be taught at the K-12 level. Vygotsky's social constructivism and Papert's constructionist learning theories may provide some insightful explanations to this doubt. As mentioned in Chapter 3 of this thesis, Piaget (1970) believed that people become capable of conducting their own learning when they are psychologically qualified at a certain age with certain levels of understanding. Vygotsky's (1978) "zone of proximal development" (p. 86) differs from the fixed biological nature of Piaget's stages of development in that an individual in a social constructivist context has the possibility to reach something beyond their age limit defined by Piaget. Vygotsky's social constructivists put emphasis on the background and culture of the learner throughout the whole learning process, as it helps to shape the knowledge in the learning process (Wertsch, 1997). According to Vygotsky (1978), the cognitive development of a child is a result of a dynamic interaction between the individual and the society which denotes a relationship of mutuality between the individual learner and the society. Children learn best in the context where the children interact and communicate with the social and cultural settings and these interactions are defined by the culture and the social-economic environment they grow up in (Steiner & Mahn, 1996). The curriculum from India is a good example of this point. When it introduces the topic of "sustainable development goals," the class discussion is on the local and global economic, environmental, educational issues. Students are given real-world problems as questions to consider and discuss, before the teacher introduces the 17 Sustainable Development Goals of the United Nations.

6.1.4 Something Old, Something New

(Socio) constructivism and constructionism hold that human knowledge is constructed, and learners build new knowledge upon their previous learning. The knowledge structure of each curriculum reflects the (socio) constructivist and constructionist ideas on knowledge building to a different extent (this will be discussed in the next section). There is an evident clue that new knowledge is built on students' existing knowledge about the world in all four selected curricula. A typical example is the curriculum from the US which is a better fit for the constructivist and constructionist ideas on this point. As the curriculum from the US focuses on ethical issues such as algorithm bias, its eight activities are closely linked in that every activity builds up to the final project by building new knowledge on the existing knowledge.

6.1.5 AI Experiences, Means or Ends

Building on and going beyond Jean Piaget's constructivist theory that emphasizes the stages of cognitive development of a child, Papert argues that a much more "interventionist approach" to children's development enables children to "concretize formal operations at a much earlier age" with more self-motivation than Piaget would expect in his constructivist theory (Fraser, 1997, p.137). Constructionism suggests that by enabling learners to build their "creative artifacts that require complex content to function," the learners will be given opportunities to "learn that complex content in connected, meaningful ways" (Berland, Baker & Blikstein, 2014, p. 206). Papert views using computers as a novel way in education that allows children to be engaged in their learning with confidence. According to Papert (1980), "The new knowledge is a source of power and is experienced as such from the moment it begins to form in the child's mind" (p.21). Artificial intelligence, in Papert's view, is more than being just an educational tool, it serves as a subject matter, a means of "liberating children's minds for much deeper and more fascinating forms of inquiry" (Berland, Baker & Blikstein, 2014, p. 206). Just like Henry Ford's famous quote "If I had asked people what they wanted, they would have said faster horses" (Walsh, 2017, n. p.), when considering the application of computers to education, people usually think about ways in which computers can help teachers in teaching those subjects they have been teaching. On the contrary, Papert proposed that the availability of low-cost computer could change people's ideas on what body of knowledge should constitute an education. To Papert (1980), computers should not just alter the ways we teach — they should also change what we teach. All the four selected curricula include training a neural network activity in their contents. Activities like these have gone beyond the means of learning AI knowledge; indeed, they are the knowledge to be learned or the necessary AI experiences to be gained by the students. Thus, hands-on activities on experiencing AI mechanism can be viewed as the subject matter itself in AI education.

6.1.6 To Code or Not to Code

Another issue is whether coding should be included as part of AI education. Among the four AI curricula, the curriculum from India is the only one that includes coding in its content. The Canadian activity assumes that students know how to code with Python to carry on the machine training activity. According to Druga (2018), "the democratization of current AI technologies allows children to communicate with machines not only via code but also via natural language and computer vision technologies" (p. 52). This makes it easier for young learners, especially K-12, to interact with and even control an AI agent via natural language such as voice. However, there is a challenge of making the process of agent reasoning transparent enough to allow the child to understand the mechanism that the machine perceives and models the world (Druga, 2018). Papert designed Logo, an educational programming language, for children to access to the "deepest ideas" of different school subjects, as he said in *Mindstorms* (1980):

> One might say the computer is being used to program the child. In my vision, the child programs the computer, and in doing so, both acquires a sense of mastery over a piece of the most modern and powerful technology and establishes an intense contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model building. (p. 5)

Thus, coding should not be a preliminary skill to start learning AI, but should be a skill for older children to further explore the technical subject matter of AI, although coding can be learned on other occasions rather than in an AI course itself.

6.1.7 Anything Missing

An interesting phenomenon is that all the selected curricula include a machine training activity in which students train a neural network that can classify images or text on digital platforms (the curricula from the US, UK and Canada) or play a unplugged human neural network game (the curriculum from India). The aim of these activities is to provide the students hands-on experience to understand the mechanism of machine learning which is an important subset of AI. These activities are supported by online platforms provided by private companies such as Google Teachable Machine, The NVIDIA Deep Learning GPU Training System, IBM Machine Learning for Kids. The curriculum from the US is the only one that includes the issue of biased data in its machine learning activity by asking the students to build a cat-dog classifier but are unknowingly given a biased dataset. However, none of them have given the students an opportunity to experience, in a similar hands-on way as machine learning is learned, a case of private data being collected and used unknowingly, to engage the students with possible issues on privacy and safety of AI. When private companies tend to normalize the collection and use of private data, educators should take the responsibility to arouse students' awareness of the negative side of AI application by letting them learn by doing and experiencing.

It is difficult to define what subject matter should be included in the AI curriculum, as AI itself is a very broad interdisciplinary field that is developing rapidly. According to Wong, Ma, Dillenbourg and Huan (2020), "research studies have not come up with a consensus of what should and what should not be in the program" (p. 24). It is challenging, even impossible, to introduce all the relevant AI knowledge at K-12 levels. Thus, the knowledge system to be included in AI education for K-12 needs to be discussed. According to Wong, Ma, Dillenbourg, and Huan (2020), "schools could devote a special attention to some of these application-driven AI algorithms" to enable K-12 students to explore how AI works (p. 22). The focus of K-12 education can be "building a clear scope of AI literacy for K-12, and categorized into three dimensions: AI concepts, AI applications, and AI ethics/safety" (p. 22). These three dimensions are in accordance with my division of the subject matters of these AI curricula. In fact, all the four AI curricula are good examples of combining AI technical knowledge with AI social and ethical knowledge with the "attention to some of these application-driven AI algorithms" (Wong, Ma, Dillenbourg, & Huan, 2020, p.22).

6.2 « Interactions between Teachers and Students of the Selected AI Curricula »

In order to discuss the "interactions between teachers, students" (Murphy, 2009, p. 35) of the selected AI curricula, the roles of teachers and students of these curricula are analyzed comparatively and discussed as a whole.

6.2.1 Comparison on Roles of Teachers of Selected Curricula

Table 11 shows the number of codes on the roles of teachers of the four selected curricula.

Table 11: Number of Codes on Role of Teacher

	Curriculum from Canada	Curriculum from India	Curriculum from the US	Curriculum from the UK
Role of teacher	17	190	144	182
Assessor	0	16	11	23
Know students	0	4	0	0
Ways of assessment	0	9	10	21
Coach	5	100	37	64
Connect to previous class	1	21	5	16
Explain	2	59	20	26
Show	2	24	12	22
Facilitator	1	2	11	15
Facilitate discussion	1	0	8	10
Offer support	0	2	3	5
Guide	6	60	76	60
Ask and prompt thinking	2	29	56	51
Check on	1	1	3	1
Remind	3	10	7	0
Organizer	6	16	15	27
Free choice	3	0	1	0
Organize activities	3	16	14	27

I generated 17 codes on the activity document for the curriculum from Canada, 190 codes on curriculum from India, 144 codes on the curriculum from the US, and 182 codes on the curriculum from the UK on the role of teacher. As the four selected curricula have different lengths and there are overlaps of the same codes in different categories, these numbers are used as comparison parameters. The curriculum from Canada does not go to the classroom level, so I use the affiliated activity as the document for this part of the study. The five themes in the role of teacher, “assessor” and “coach”, “facilitator”, “guide” and “organizer” (highlighted with a light green background) vary in their relative weights. As shown in Table 11, the teacher in the curriculum from Canada mostly acts as a “guide” and an “organizer” in the teaching. The curriculum from Canada has the largest proportion of codes on “free choice” among all the four selected curricula. The teacher organizes class activities and has the greatest freedom in choosing what and how to teach. The major role of the teacher in the curriculum from India is a “coach” who trains the students by showing, explaining, and making connections among lessons. “Explaining” is the most frequently coded action of the teacher in the curriculum from India. The curriculum from India is the only one in the four selected curricula that has the teacher know the students’ backgrounds. Differently, the curriculum from the US has more codes on “guide” as the role of teacher. Student learning is guided by the teacher by asking questions and prompt thinking. Again, in terms of subject matter, the curriculum from the UK is the most balanced in that the five roles of teacher are the most evenly distributed. Similar to the curriculum from the US, the teacher in the curriculum from the UK mainly teaches by asking questions and prompting thinking.

6.2.2 Comparison on Roles of Students of Selected Curricula

Similar to the roles of teachers, the roles of students are compared. Table 12 shows the number of codes on the roles of students of the four selected curricula.

Table 12: Number of Codes on Role of Student

	Curriculum from Canada	Curriculum from India	Curriculum from the US	Curriculum from the UK
Role of student	12	182	103	205
Critical thinker	1	84	22	59
Critical thinking	0	5	0	0
Reflection	1	51	16	45
Self-directed learning	0	26	6	17
Solve problem	0	5	0	0
Explorer	8	74	51	49
Design build things	2	23	19	17
Examine explain	1	5	10	16
Explore and identify	5	42	22	5
Research	0	7	0	11
Team worker	3	39	38	109

Group activity	0	22	14	23
Sharing ideas	2	14	19	81
Teamwork	1	3	6	10

I generated 12 codes on the activity document for the curriculum from Canada, 182 codes on curriculum from India, 103 codes on the curriculum from the US, and 205 codes on the curriculum from the UK on the role of student. As the curricula have different lengths and there are overlaps of the same codes in different categories, these numbers are used as comparison parameters. Also, the curriculum from Canada does not go to the classroom level, so I use the affiliated activity as the document for this part of the study. As shown in Table 12, the four selected curricula put different weights on the three themes on the role of student: “critical thinker” and “explorer” and “team worker” (highlighted with a light green background). The students in the curriculum from Canada mostly act as an “explorer” in their learning, as the curriculum from Canada has the largest proportion of codes on “explore and identify” among all the four selected curricula. The students learn by exploring things and identifying knowledge. Similarly, the major role of students in the curriculum from the US is an “explorer” who learns by exploring and identifying knowledge, examining and explaining phenomena, and designing and building things. The curriculum from the US has the largest proportion of codes on “design build things” among all the four selected curricula. This shows that the curriculum from the US provides students with more chances of learning by doing. In terms of the roles of students, the curriculum from India is the most balanced curriculum among the four selected curricula in that the codes on the three roles of students are the most evenly distributed, and every theme and category is covered by the curriculum. The curriculum from India is the only one in the four selected curricula that has singled out “critical thinking” as an objective of learning AI and covers “solve problem” in “role of student” and “critical thinker” is the most frequently coded role of the student in the curriculum from India. Students in the curriculum from India make regular reflections in class and self-direct their own learning. Also, “explore and identify” comes as the largest proportion in student’s actions in class which means the students in the curriculum from India learn mainly by exploring and identifying knowledge besides being a critical thinker. Differently, in the curriculum from the UK, more than half of the codes (109:205) on the role of students belong to the theme of “team worker” in which “sharing ideas" become the largest amount of codes on the category. The curriculum from the UK emphasizes sharing learning with peers.

6.2.3 Student-Centered Teacher-Student Relationship

(Socio) constructivism and constructionism believe that students are a central part of the classroom. Piaget's (1970, 1971) theory of constructivism asserts that knowledge is not simply transmitted from teacher to student, but actively constructed in the mind of the learner. Building from the idea of constructivism, Papert's (1980) constructionism suggests that new ideas are most likely to be created when learners are actively engaged in building some type of external artifact that they can reflect upon and share with others. Based on these learning theories, the teacher-student relationship has changed from that of the traditional classrooms in which the teacher dominates the class. In constructionist learning, delivering knowledge to students is replaced by helping them to comprehend, and assist their peers to comprehend problems in a hands-on way (Papert & Harel, 1991). A constructivist teacher acts as a facilitator who allows the students to investigate, create, and solve problems in collaboration, feedback and reflection. A constructionist teacher also serves as the creator of a learning environment in which the teacher works together with the students to help them learn and grow.

Table 11 shows that in general, the teachers' roles in the four selected curricula have shifted from the sage on the stage to a combination of roles of a creator of a classroom environment and a facilitator to help learners as they explore and attain personally meaningful goals. Besides being a coach and assessor, the teachers of the selected AI curricula play the constructionist role of a facilitator, an organizer, a guide, working with students to inquire and address meaningful questions, structuring authentic tasks, teaching AI knowledge and coaching social skills, and assessing student performance in multiple ways. Also, as Schwab (1973) explained that teaching must include the "general knowledge of the age group under consideration: what it already knows, what it is ready to learn, what will come easy, what will be difficult" (p. 502), to respect a student's background, a constructionist teacher should know the strengths, weaknesses, and limits of the students. The curriculum from India is a good example in that it includes most information on getting to know the students. At the same time, students mainly learn by exploring, designing and building things, examining and explaining. The curriculum from the US and the curriculum from the UK are more on the constructionist side in that their teachers act more as a facilitator and a guide in their roles while giving more freedom to the students to explore by themselves or with their peers. In both curricula, “ask questions and prompt thinking” tops the list of the roles of teachers, as the major role of constructionist teachers is to help students explore knowledge by themselves. Compared to the other three curricula, the curriculum from India is more on the traditional side in that the major role of teacher is to coach by showing and explaining.

6.2.4 Independent Students

Constructivist classrooms create motivated and independent learners in lessons that include guided discovery, whereby the teachers act as a guide to the learner, helping to point out inconsistencies in students’ thinking. Students build their understanding by resolving these conflicts. Constructionism theory also advocates that each student should work on their own to acquire something useful and valuable for their knowledge, so students should be self-directed in their learning process and should reach their own conclusions through creative real-world experimentation. Three of four curricula include “self-directed learning” as important elements in the role of students.

Constructivism proposes student-centered, discovery learning where student agency is emphasized to acquire more knowledge (Alesandrini & Larson, 2002). Based on this idea, constructionism believes that learning occurs most effectively when students are actively making tangible social objects (physical or digital objects) in the real world (Ackermann, 2001). An important role of a constructivist teacher is to set up proper learning environment that will foster student’s individual learning and present problems to be solved, leaving the students to explore on their own without any further intervention (Rob & Rob, 2018). A good example of this idea is the curriculum from the US. In the sample activity introduced in Chapter 5, the teacher in the curriculum from the US demonstrates Google’s Teachable Machine to the students and gives them the task to train and test datasets. Then, without instructing the students how to train the dataset, the teacher only checks on and offers support if necessary, as students work through the activity, leaving the students much freedom to learn by themselves and from each other.

6.2.5 Peer Interactions

Like social constructivism, constructionism promotes that learning occurs through a collaborative process which incorporates peer feedback. Students learn from collaborating with others in constructionist classrooms. Because many peer interactions occur in a constructionist classroom, the constructionist teacher needs to “organize activities” and “facilitate discussion” to foster cooperation among students as demonstrated in the role of teacher in these curricula. Also, the teacher should provide for the child model behaviors and/or verbal instructions referred to by Vygotsky as cooperative or collaborative dialogue as children and their partners co-construct knowledge. Students in the four curricula all learn from sharing their understandings with their peers, while the curriculum from the UK emphasizes teamwork among students as “sharing ideas” tops the list of the role of students.

6.3 « Milieux of the Selected AI Curricula »

In order to discuss the “learning environment” (Murphy, 2009, p. 35) of the selected AI curricula, the milieux of these curricula are analyzed comparatively. When defining the four commonplaces, Schwab (1973) identifies the milieux as “the school and classroom in which the learning and teaching are supposed to occur [...] the family, the community, the particular groupings of religious, class, or ethnic genus” (p. 503). Each of these environments is essential in the education of children, in understanding who the students are, what are their backgrounds in education, the influence that their parents and community have on them, how they relate to their peers, and, ultimately, who they can become if only they are properly educated.

6.3.1 Comparison on Milieux of Selected Curricula

Table 13 shows the number of codes on the milieux of the four selected curricula.

Table 13: Number of Codes on Milieu

	Curriculum from Canada	Curriculum from India	Curriculum from the US	Curriculum from the UK
Milieu	50	79	50	65
Digital environment	30	24	20	24
Web resources	28	16	5	22
School environment	9	11	1	0
Class size	0	8	0	0
Social environment	11	8	1	1
Teaching tools and materials	1	36	29	40
Stationaries	0	36	17	30
Technological tools	1	0	10	10

I generated 50 codes on the curriculum from Canada, 79 codes on curriculum from India, 50 codes on the curriculum from the US, 65 codes on the curriculum from the UK on the milieu. As the curricula have different lengths and there are overlaps of the same codes in different categories, these numbers are used as comparison parameters. The four themes in milieu "digital environment", "school environment", "social environment", and "teaching tools and materials" (highlighted with a light green background) vary in their relative weights. As shown in Table 13, the curriculum from Canada has the largest proportion of codes on "social environment." Here is an example for the social environment:

> In early 2019, Actua set out to address this need in engaging youth in AI. With support from Google.org and the Canadian Internet Registration Authority (CIRA), we created Actua's AI Project, designed to contribute to the development of a strong AI training ecosystem in Canada (p. 4).

The ecosystem of AI education in Canada is introduced as the social milieu. Also, the curriculum from Canada has the largest amount of codes on "digital environment" with the largest number of "web resources" among all the four selected curricula. The curriculum from India is the only curriculum that specifies "class size" in each lesson plan. The class size is set on 40 students, which would seem a hard job for teachers in an activity-based, experiential-learning and inquiry-based learning environment as stated in the curriculum from India, but understandable concerning the population of India. Again, the curriculum from India is the most balanced in terms of the milieu in that the four kinds of milieux are the most evenly distributed. It has the most codes on school environments. For example, it illustrates the school environment for teaching AI in the "About the Book" section as:

> CBSE is already offering various Skill subjects at Secondary and Senior Secondary level to upgrade the skills and proficiency of the young generation and also to provide them awareness to explore various career options. At Secondary Level, a Skill subject may be offered as additional sixth subject along with the existing five compulsory subjects. (n.p.)

The school context for AI education is introduced as the milieu. On the contrary, the curriculum from the US has the least codes on "web resources" as it clearly states that most of its class activities are unplugged. The curriculum from the UK has the most proportion of codes on "Teaching tools and materials," partly because it has a separate section for resources with a list of web resources in each lesson plan.

6.3.2 Authentic Environments

Constructivism emphasizes an authentic task in a meaningful learning context rather than abstract instruction out of context. According to Jonassen (1994), real-world settings or case-based learning environments can be created in constructivist classrooms where tools are developed to meet the constructivist suggestion that students learn best in authentic environments, using the complexity and richness of real-world examples. The "Smart city, home, and school design" in the curriculum from the UK, the "Dream Smart Home Activity" in the curriculum from India, and "YouTube redesign" in the curriculum from the US are good examples in this case. Among the selected curricula, the curriculum from the US fits the constructionist idea best in that students explore AI knowledge in authentic environments, using the variety and complexity of real-world examples where problems occur and wait to be solved.

6.3.3 Computational Environments

Papert advocated "the construction of educationally powerful computational environments that will provide alternatives to traditional classrooms and traditional instruction” (p. 182). His idea is clearly stated in his landmark book, *Mindstorms: Children, Computers, and Powerful Ideas* (1980):

> Before computers there were very few good points of contact between what is most fundamental and engaging in mathematics and anything firmly planted in everyday life. But the computer — a mathematic-speaking being in the midst of the everyday life of the home, school, and workplace — is able to provide such links. The challenge to education is to find ways to exploit them. (p. 47)

However, different from the curricula from the UK and Canada that mainly set their teaching in plugged settings, the curricula from the US and India are mainly unplugged. It is worth noting that the curriculum from the US designs seven unplugged activities out of eight activities (including one activity with both plugged and unplugged versions) to fit into traditional classroom settings. As the Wall Street Journal reported, the MIT “unplugged” curriculum mainly uses pen, paper and craft supplies so that teachers can adapt it for their classrooms, regardless of budget or technological know-how” (Ma, 2019). Papert (1980), the forefather of MIT Media Lab, focused his work on how technology can provide new ways to learn and teach mathematics, thinking in general, and other subjects. Papert insisted on the idea of an inexpensive personal computer for every child, like a notebook and a pencil as instrument for learning and enhancing creativity, innovation, and “concretizing” computational thinking, although it was then regarded as a science fiction 1960s. It is interesting that in such a time when digital equipment has become common in education in most areas of the world, the curriculum from the US is sticking to the pencil-and-paper version of classroom activities, regardless of the fact that Papert advocated the idea of a personal computer for every child 60 years ago.

6.3.4 Tools

As part of authentic learning environments, tools form an important element in AI teaching. To Papert, computers serve as the tools to set up powerful computational environments for teaching. One of the classic quotations on the use of the computer as a tool from Papert (1980) is “For me, the phrase ‘computer as pencil’ evokes the kind of uses I imagine children of the future making of computers. Pencils are used for scribbling as well as writing, doodling as well as drawing, for illicit notes as well as for official assignments (p. 210).

According to Touretzky, Gardner-McCune, Breazeal, Martin, and Seehorn (2019), "the range of AI topics students are able to explore is closely tied to the availability of developmentally appropriate tools for K–12" (p. 89). The selected AI curricula for K–12 make use of various materials from traditional stationaries such as pencils and paper to interactive media such as "DIGITS" and "Google's Teachable Machine" and online resources for activity-based learning opportunities. Touretzky et al. (2019) highlight that "a number of these platforms integrate commercial cognitive services, AI tools, and datasets developed by university or corporate research laboratories to provide user-friendly tools for K–12 students" (p. 89).

6.4 « Pedagogical Approaches of the Selected AI Curricula »

Based on the above discussion on the role of teacher, the role of students, and the milieu of each curriculum, the following is a holistic discussion on the pedagogical approaches applied to the four curricula. Table 14 shows the pedagogical approaches of the four curricula I concluded from the analysis of their role of teacher, role of students, and milieu.

Table 14: Comparison of Pedagogical Approaches of the Four Curricula

	Curriculum from the US	Curriculum from the UK	Curriculum from India	Curriculum from Canada
Major Role of Teacher	guide	coach, guide	coach	guide, organizer
Major Role of Student	explorer	team worker	critical thinker	explorer
Major Milieu	stationaries	stationaries Web resources	stationaries	web resources
Pedagogies	project-based, activity-based, cooperative	inquiry-based, cooperative	activity-based, experiential, inquiry-based	activity-based, experiential

As discussed earlier in Chapter 5, the curriculum from India states clearly that "hands on – activity based, experiential learning, inquiry-based learning" (p. 6) are pedagogies applied to their AI teaching. The curriculum from India organizes teaching through class activities, in which the students are prompted to think, explore, and reflect upon their experiences. Traditional teaching methods are also used as the teacher coaches by showing, explaining, and organizing written examinations, although these teaching methods are not written in the curriculum itself. The curriculum from the US applies activity-based, project-based, and cooperative-learning approaches. It emphasizes student's exploring and building things through "activities" and "games and competitions." The activity plan affiliated to the curriculum from Canada applies activity-based, experiential-learning approaches. Students' learning is guided by the teacher who asks questions and prompts thinking. The students in the activity plan from Canada learn mainly by exploring things and identifying knowledge when the teacher guides and organizes activities. The curriculum from the UK applies inquiry-based, cooperative-learning approaches. Students in the curriculum from the UK learn mainly in teamwork to look for answers prompted by their teacher.

Project-based learning, activity-based learning, inquiry-based learning, cooperative learning and experimental learning are all important (Socio) constructivist and constructionist pedagogical approaches. (Socio) constructivist and constructionist propose student-centered, discovery learning where student agency is emphasized to acquire more knowledge. Constructivism (Piaget, 1969; Vygotsky, 1978) holds that learners construct their individual knowledge through interactions with their environment. Constructionism goes even further by proposing that individuals learn best when they are constructing an artifact that can be shared with others and reflected upon, such as plays, poems, pie charts or toothpick bridges, etc. (Harel & Papert, 1991). Students must actively participate in learning because the teacher does not just provide answers. The teacher facilitates learning rather than act as an authority who transmits textbook knowledge to students. Students are given real-world problems to think upon and small projects to solve these problems. Experimental learning provides students the opportunity to try and explore the problems they encounter. Through problem solving, students set up a non-linear process of collective knowledge-construction to present new contents with their classmates (Vygotsky, 1978). Learning depends on the shared experiences of students, peers, and the teacher. Collaboration with others is so important that cooperative learning becomes an important pedagogical approach used in both social constructivist and constructionist classrooms. The pedagogies of the four AI curricula for K-12 all have some features of these learning theories. Among the four selected curricula, the curriculum from the US is the best fit for (socio) constructivist and constructionist learning theories in that the students are given the most freedom to learn by themselves through hands-on activities. Compared to the other three curriculum, the curriculum from India applies more traditional pedagogical approaches in that the teacher shows and explains knowledge to the students after asking them questions as prompts of thinking and organizes quizzes at the end of each class section, although it is also influenced by constructionist ideas.

In conclusion, the following features stand out of the selected curricula:

First, the four curricula all cover a significant amount of technical and social and ethical subject matters aiming at introducing AI knowledge and bringing AI experience to K-12. However, they have different foci in their choices of subject matters. The curricula from Canada and India put more emphasis on the technical aspects of AI knowledge with the curriculum from India covering coding in its content, while the curriculum from the US focuses more on social and ethical subject matters. The curriculum from the UK is the most balanced in terms of contents.

Second, in terms of roles of students and teachers, all curricula are student-centered. Independent learning and peer interactions are emphasized with teachers serving as facilitators, organizers, guides, and coaches instead of knowledge deliverers, and students acting as self-directed learners. However, the roles of teachers and students vary among these curricula. The curriculum from the US offers the students the greatest opportunities to learn by doing while the curriculum from Canada offers the teacher the greatest pedagogical freedom.

Third, the four curricula all emphasize authentic and computational learning environments with careful selection of teaching tools. However, their design of the learning milieux differs. The curricula from the US and India are mainly unplugged while the curricula from the UK and Canada are plugged. The curriculum from Canada emphasizes social environment while the curriculum from the UK stresses teaching tools and materials.

Last, the four curricula all apply student-centered (socio) constructivist and constructionist pedagogical approaches such as project-based learning, activity-based learning, inquiry-based learning, cooperative learning, and experimental learning which are interweavingly used. The curriculum from the US is the best fit for constructionism, while the curriculum from India is most inclined to use traditional approaches.

These AI curricula provide educators and researchers in the field of AI education meaningful and valuable examples to use, study, and learn from. However, they are not perfect. Among the selected curricula, the curricula from the UK and India cover a wider scope of knowledge and skills. The curriculum from the US has covered only limited knowledge of technical aspects of AI, and the curriculum from Canada only provided limited activities for classroom reference. Also, the potential issues of AI are inadequately stressed in the selected curricula. It is interesting that all four curricula include a machine training activity where students imitate processes for image recognition without having an opportunity to experience a case of possible issues on privacy and safety of AI in a hands-on way. There is much to do to include more carefully designed hands-on activities to implement the learning goals of AI. As AI curriculum development itself is on a primary stage, the lack of well-accepted standards for curriculum design may be the reason that these curricula vary so much in their choice of contents, the corresponding pedagogies, and even the formats.

Chapter 7

7 « Conclusion »

Curriculum study on AI curricula is a new topic in the field of educational studies. This study is significant as it will be one of the first of its kind to be done on AI curricula. The results of this study will shed light on research on AI education in general and for K-12 especially, as AI education is a new focus without much research done on AI curriculum. Moreover, this research can form part of the existing empirical evidence about interpreting AI educational practices to educational practitioners in AI curriculum study and design as to the challenges and successes of curriculum reform focused on AI education at all levels. This research could guide curriculum designers in constructing AI curricula for different purposes, guide teachers in choosing proper teaching contents and methods to organize AI learning to suit different levels of students, and arouse parents' awareness of AI education as an important part of preparing the future of their children. Also, this study will be valuable to governments in educational policymaking in the field of AI education and STEM education in general as it provides a comparative analysis of what is offering now as experimental data on K-12 AI curriculum development.

Several lines of research may emerge from this study. First, in regard to research scale, as mentioned in chapter one, a limitation of this research is that only four curricula are included in this study. A more inclusive study may lead to a clearer picture of the current situation on AI K-12 education when more AI curricula are available. Second, in regard to research scope, three topics of research may follow. 1) As many researchers suggest that AI education could be integrated into other existing school curricula such as Computer Science or Social Studies, future research could expand to the study of what AI knowledge should be integrated into other existing school subjects and when. 2) Comparative studies on the two trends of AI education (establishing new AI courses or integrating AI knowledge into other courses) are significant in studying the future direction of AI educational reforms. 3) When developing the topic of comparative studies on AI curricula and AI educational reform, some opportunities for research emerge in exploring the impact of the cultural, economic and political factors that affect the contents and pedagogical approaches of AI curricula and vice versa. Third, in regard to research methods, there are many avenues to explore in AI K-12 education. Based on the findings of what basic elements are included and what pedagogical approaches are involved in the existing AI curricula, future research may apply grounded theories to form possible theories on the general trend and standard of AI K-12 education. Also, it is meaningful for future research to focus on in-depth case studies on individual AI curriculum which may include the classroom feedback from the students, teachers as well as parents and other stakeholders of education. Figure 24 shows the possible future research.

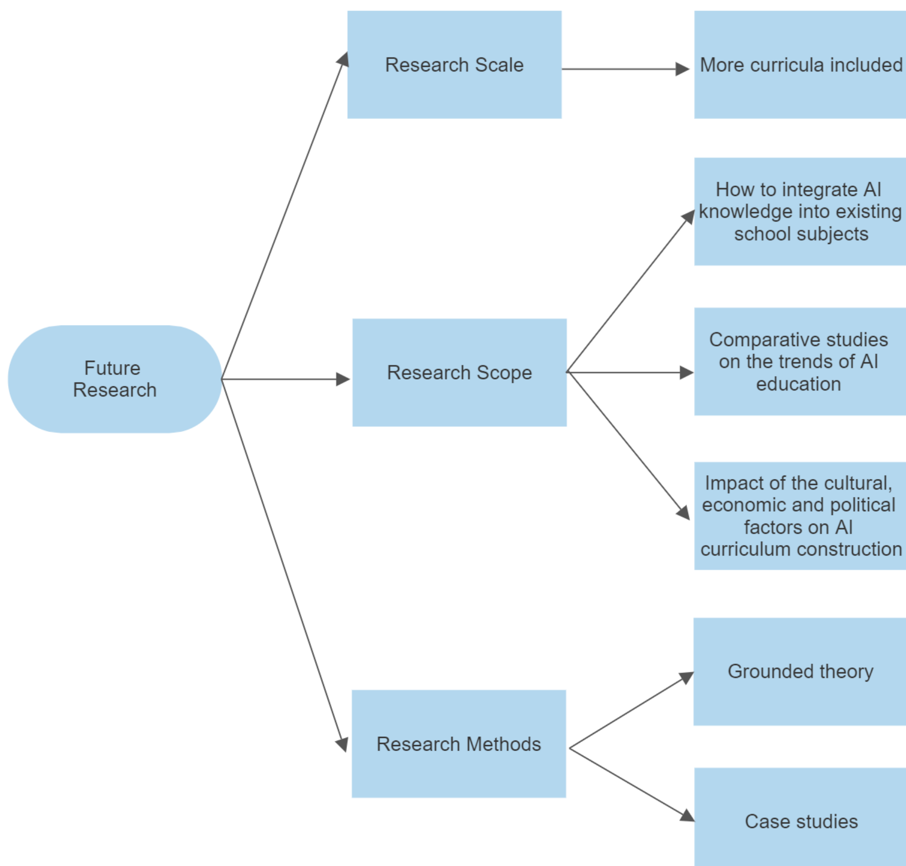

Figure 24: Future Research

It is my sincere hope that researchers and practitioners can use the knowledge of this thesis to design, implement and/or modify AI curriculum to best fit their students' needs, an AI curriculum that opens a wide wall, sets a firm floor, and builds a promising ceiling to the students to help them explore an AI world with curiosity and satisfaction.

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