Chapter 9
Exploring the Challenges of Teaching Mathematics During the Fourth Industrial Revolution in Selected Rwandan Secondary Schools

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Introduction

Industrial revolution (IR) refers to the transformation of the economy based on agriculture and handcraft into an economy based on industry and machines (Mohajan, 2019). The first industrial revolution started in 1760 with the discovery of the steam engine machine for the transformation of agricultural products; textile and steel were the dominant industries (Agarwal & Agarwal, 2017). The second industrial revolution started in 1900 and was characterized by rapid industrialization using oil and electricity to power mass production (Xu et al., 2018). During the second industrial revolution, the steel and chemicals industries dominated (Agarwal & Agarwal, 2017). The third industrial revolution began in 1960 with the development of the computer and internet (Taiwo, 2020). During the third IR, industries were based on science and technology (Brian, 2015). Computerization and web-based learning started in the third IR (Gleason, 2018). The fourth industrial revolution (4IR) boost Mathematics, science, and technology. The fourth industrial revolution started in 2000 and was characterized by the development of green energy industries, artificial intelligence, machine learning, robotics, and 3-D printing. In recent times, the internet is becoming faster, more accessible, and more mobile. At the same time, information can easily be manipulated within a short time through the increase in data storage and processing capacity (Taiwo, 2020).

Education in the 4IR emphasizes that students learn science and technology that enable them to live in society and be successful workers. People must have the skills required to implement, manage and work with the new technology and with one another (Butler-Adam, 2018). Now days use of technology help students to become

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problem solvers, Critical thinker, and decision-maker in society. 4IR requires changing the method of teaching mathematics. Teachers must adopt a new teaching methodology, be creative and innovators and create new learning opportunities (Naidoo & Singh-Pillay, 2020). It was found that the practice of teaching and learning mathematics remains dominated by the manipulation of symbols with the paper-and-pencil medium (Ng & Tsang, 2021).

Teaching methods of mathematics include lecture, inductive, deductive, heuristic or discovery, analytic, synthetic, problem solving, laboratory, and project methods. Teachers may adopt any method according to the specific unit of the syllabus, available resources, and the number of students in a class (Baig, 2015). Effective teaching and learning mathematics requires an effective method that helps students think and develop competencies. Rwanda has adopted a new curriculum called the Competence-Based curriculum from the Knowledge-Based curriculum in 2015, which focused on a learner-centred approach. It was found that Rwandan mathematics teachers were aware of learner-centred pedagogy. Some methods used by Rwandan mathematics teachers are question-answer, group discussion, and experimentation. The common method used by Rwandan mathematics teachers are question-answer and group discussions (Nsengimana, 2017).

In 4IR, the research shows that effective teaching and learning science, technology, engineering, and mathematics (STEM) is encountering different challenges. According to Ng and Tsang (2021), school teachers have often expressed that they have inadequate knowledge and resources to integrate STEM concepts and practices in their classrooms. Rwanda mathematics teachers encounter some challenges in their work. Research conducted in Rwanda showed that teacher knowledge and skills in the learner-centred approach are insufficient. It was found learner-centred approach is limited to simple oral questioning, group discussion, and experimentation or doing exercises (Nsengimana, 2017). It was also found that there was a lack of teaching materials to accommodate a Competence-Based Curriculum, a large number of learners in a classroom, low level of learners, and English language problems for teachers and learners (Ndihokubwayo & Habiyaremye, 2019). More research on the challenges of teaching mathematics was conducted. However, this study tends to investigate challenges uncounted by Rwandan mathematics teachers in the teaching and find potential solutions to those challenges to meet the needs of students in the 4IR. The study's results will help teachers design instructional activities that qualify students for future jobs. In the future, the problem could not be the lack of jobs but the skills shortage that will depend completely on IR 4.0 ideas.

Literature Review

Philosophy of Mathematics Education

Mathematics education enables people to see beyond the stories of society as it helps us imagine different possibilities. The aims, goals, purposes, and rationales of teaching mathematics should be related to society (Ernest et al., 2016). Ernest

(1998) proposed two mathematics philosophies, absolutist and fallibilist. Fallibilist philosophy of mathematics believes that mathematics is a human construct. In the fallibilist philosophy, mathematics is no longer knowledge that is simply memorized in a rote fashion. It is societal knowledge that must be interpreted in a manner that holds meaning for the individual. According to Ernest (1998), the other mathematics philosophy is absolutism. Absolutists believe that mathematics is a divine gift. Mathematics is considered a cultural product or a human activity complete with cultural, historical, and humanistic aspects, that is, "a dynamic, continually expanding field of human creation and invention, a cultural product" (Ernest, 1998). Knowledge and skills in mathematics can be constructed socially, meaning that knowledge is constructed through interaction with others (Izmirli, 2020). According to (Anthony & Walshaw, 2009), they are ten effective methods that stimulate effective teaching and mathematics, including classroom community, arranging for learning, mathematical communication, mathematical language, worthwhile tasks, making connections, tools and representation, and teacher knowledge. The study conducted by Mazur (2011) found that mathematical tasks as an important method in shaping the system of basic mathematical knowledge, abilities, and habits in students. It was also found that independent learning and research work as methods that help students' problem-solving skills and develops their creative thinking processes and skills. In addition, the research conducted by Khan et al. (2021) among 33 government colleges in Punjab, Pakistan, found that most teachers use teaching methods that connect theory and practice, question and answer techniques to explain mathematical concepts.

An Overview of Mathematics Education and the Fourth Industrial Revolution

The fourth industrial revolution is known as the assemble of physical resources, innovative digital technologies, non-natural aptitude, robots, drones, autonomous vehicles, 3D printing, cloud computing, and more that interconnect, investigate, and enable civil service and society to be malleable (Xu et al., 2018). It involves how technologies like artificial brainpower, self-governing vehicles, and the internet are integrated with individuals' physical lives (Fomunyam, 2020). Mathematics education is one of the most important subjects which can help to fit into 4IR goals, not only to provide sustainable education but also to promote core values and qualities of social justice (Moloi & Matabane, 2020). The teaching and learning of mathematics is an approach to teaching that seeks to permit students to gain the required skills for world challenges. Nowadays, there is an emphasis on incorporating technology into the teaching and learning of mathematics to produce educated citizens who can function in 4IR. The sustainability of mathematics classroom practices is enhanced when 4IR realizes human possibility and promotes core values and qualities of social justice. For mathematics classroom practice to be active and sustainable, cultural practices and surviving experiences of learners must be incorporated into our teaching and learning. 4IR orders the way students have to be taught.

Learners must experience work places and have the knowledge and think about the 4IR. Instructors and students have to keep up with the pace of industrial advancement. If not, they can be left behind (Ilori & Ajagunna, 2020).

The current curriculum utilized in African education is ancient and irrelevant to the needs of the 4IR. Many topics of this curriculum do not prepare learners with the required skills to perform the upcoming civil service tasks (Fomunyam, 2020). Mathematics Education is not strong, and this impacts the number of learners who choose mathematics as a specialized carrier. It is attributed to the low number of mathematics teachers in Africa. It is paramount to implant in the young generation the ability to study mathematics and equip them with the necessary skills.

Method of Teaching Mathematics in Rwanda in 4IR

According to Rwanda Basic Education Board (REB), a new curriculum called Competence-Based curriculum launched in 2015 proposed different teaching methods in teaching mathematics in ordinary or advanced levels in Rwandan secondary schools, including practical, group discussion, mental task, presentation, research work, questioning, and demonstration (REB, 2015). They are limited literature about mathematics education in Rwandan secondary schools. This section highlighted teaching methods used in teaching mathematics in Rwanda based on available literature. According to (Nsengimana et al., 2017), most teaching methods of teaching mathematics at ordinary levels are peer learning, group work and expository methods. Most activities done in the classroom are doing homework, doing exercises, taking a summary of the lesson notes, and reading math books (Ukobizaba et al., 2019). Nsengimana (2017) found that Rwandan mathematics teachers use traditional teaching methods, classroom activities, research, problem-solving, practicals, group discussion, and questioning methods. The research conducted by Uworwabayeho (2009) found that using Geometer's Sketchpad improves students learning. Gichuru et al. (2016) found that ineffective teaching methods result in poor performance in math. This research found that group discussion, learning in pairs, and demonstration are mostly used by Rwandan teachers.

Challenges Encountered by Teachers During Teaching Mathematics in 4IR

Mathematics is a subject that has a significant contribution to society. However, teaching mathematics has been uncounted by different challenges. This section discusses the challenges mathematics teachers face in the teaching and learning process. The study of Assessing the Challenges of Learning and Teaching of Mathematics in Second Cycle Institutions in Ghana conducted by Peter et al. (2014) indicated that lack of teaching and learning materials, poor attitude towards

teaching by teachers, fear of mathematics, abstractness nature of mathematics concepts, limited mathematics periods, incompetent teachers, poor teaching methods, and inconsistent curriculum as major challenges that hinder effective teaching and learning mathematics. These challenges agree with Mutarutinya et al. (2020), who found that inadequate skills for conducting practical science and a lack of permanent friendly professional development program are challenges encountered by Rwandan mathematics teachers.

The research conducted by Gafoor and Kurukkan (2015) in Malappuram and Kozhikode districts in Kerala, India, found that big class size, lack of relevant prerequisites, the reluctance by students to seek support from others, poor motivation of students, and difficulty in the speedy grasping the concepts as major challenges that hinder effective teaching and learning of mathematics. They also found that planning for teaching mathematics, executing mathematics lessons, and assessing are obstacles mathematics teachers face in their teaching. The study by Darkis (2020) showed that it is difficult to integrate technology in mathematics classrooms for mathematics teachers in rural areas. In addition, teachers responded that mathematics does not respond to the needs and interests of students in rural areas. Insufficient teaching aids and poor teaching methods lead to mathematics difficulty (Sakilah et al., 2018). Using the traditional methods in teaching mathematics makes students inactive and not creative (Tanujaya et al., 2017).

Research Questions

- What challenges do teachers and students encounter while teaching mathematics in Rwandan secondary schools during the fourth industrial revolution?
- What are challenging mathematics topics to teach and learn in Rwanda in the fourth industrial revolution?

Methodology

The target population was all 328 mathematics teachers from ordinary level and advanced levels from three districts in Rwanda, namely Kayonza, Rwamagana, and Gatsibo districts, Rwanda. However, a total of 109 mathematics teachers comprised, 76 males and 33 females, were randomly selected from the government, public and government-aided schools. A simple random sampling was used where the participant was selected after the third participant. Simple random sampling is useful because it allows all the units in the population to have an equal chance of being selected (West, 2016). A Likert scale questionnaire composed of 68 rating multiple-choice questions was used to explore challenges and their potential solutions and investigate challenging topics uncounted by Rwandan mathematics teachers in their teaching.

The questionnaire was developed by the researcher in close collaboration with experts in Mathematics education from the University of Rwanda, College of Education. Descriptive statistics such as mean and standard deviation was used to analyze data. To confirm the content validity and reliability of the research instrument, the questionnaire was tested and approved by an expert in research and mathematics education from the University of Rwanda, college of education (UR-CE). The research instrument was piloted on 37 secondary school mathematics teachers. This was done to ensure the internal consistency of the instrument. The reliability coefficient was calculated by using Cronbach's and was found to be 0.86. The anonymity and confidentiality of the respondents were preserved by not revealing their identification in the collection of data, data analysis, and presentation of findings. All individuals were willing to participate in this study.

Findings and Discussion

Challenges of Teaching Mathematics in 4IR

A Likert scale questionnaire with five levels was used to measure challenges faced by mathematics teachers in 4IR. The levels were: very low extent = 1, low extent = 2, moderate extent = 3, high extent = 4 and very high extent = 5. Findings were descriptively analyzed in terms of mean, standard deviation and variance. Among 21 statements related to the challenges faced by teachers in teaching mathematics in secondary schools, only 15 showed that there were difficulties uncounted by mathematics in their teaching. Teacher's responded at most that abstractness nature of mathematics ($\bar{x}$ = 4.1009, SD = 0.8271), time for planning lessons ($\bar{x}$ = 4.0275, SD = 0.92755), teaching materials ($\bar{x}$ = 4.0275, SD = 0.85482) and classroom size ($\bar{x}$ = 4.2661, 82,398), at most that make mathematics difficult to teach. The teacher's agreements are illustrated in Table 9.1 below.

The result from the above Table 9.1 revealed that mathematics teachers are faced many challenges in their teaching. Teachers reported 15 challenges faced by them in their work, including abstractness of nature of mathematics, time allocated and planning lessons, lack of CPD, Change in the curriculum, lack of technological tools, Uninterested students, lack of teaching materials, poor work habits of students, lack of support from parents, negative peer influence and poor motivation of students, too much content and class size. Other authors support the above results and found that the nature of mathematics and the negative perception of students make mathematics difficult to understand. The research conducted in secondary schools in Bangladesh showed that most students fail mathematics because of a lack of teaching materials and most teachers are not adaptable to modern methods of teaching mathematics (Khaleduzzaman, 2020). A study conducted by (Koji et al., 2016) in the four selected secondary schools in Mufulira district, Zambia, found that a lack of pre-requisite knowledge by pupils; lack of conceptual, procedural, and

Table 9.1 Descriptive analysis of challenges faced by teachers in teaching mathematics

Statements	N	Mean	Std. deviation
Large classes size	109	4.2661	0.82398
Mathematics is primarily an abstract subject	109	4.1009	0.82710
Teaching materials are not enough to teach mathematics	109	4.0275	0.85482
Time for planning lessons is not enough	109	4.0275	0.92755
Too much content in the curriculum	109	3.9174	0.94407
Lack of continuous professional development (CPD)	109	3.9083	0.95783
I have difficulty keeping up with all of the changes to the curriculum	109	3.8624	1.18218
Poor work habits of students	109	3.8532	1.13713
Lack of student effort/motivation	109	3.8440	1.09014
Teachers do not have adequate technological resources	109	3.7156	1.09791
Uninterested students	109	3.6606	.98338
Negative peer influence	109	3.6514	1.00348
Lack of support from parents/guardians	109	3.3853	1.21646
Time allocated to teach mathematics is not enough	109	3.2752	1.21618

strategic knowledge and skills required for solving linear equations; and inappropriate approaches and methods as challenges that hinder effective teaching of algebraic linear equations. Low tests or exam scores, teachers' harshness, and carelessness were reported among the factors demotivating students to like Mathematics (Ukobizaba et al., 2021). The study by Nsengimana et al. (2017) showed that Rwandan mathematics teachers have limited knowledge of learner-centred pedagogy.

Potential Solutions to the Challenges of Teaching and Learning Mathematics

To investigate the potential solutions to the challenges associated with teaching mathematics, ten rating multiple-choice questions and one open question were used. The mean value, standard deviation and variance were calculated on agreement of a three-point scale (*slightly valuable = 1, somewhat valuable = 2, and very valuable = 3*). Potential solutions are classified into two categories, including teaching and learning materials and teaching methods. Table 9.2 shows the solutions to the teaching and learning materials, while Table 9.3 shows solutions to the teaching method. Teachers indicated that computer software, calculators, web-based resources, and manipulative materials are potential tools in teaching and learning mathematics. They also pointed out that using class discussion, problem-solving, group work, practicals, and alternative methods of finding solutions are potential teaching methods of mathematics that can help them in their teaching.

Evidence shows that the continuous profession of in-service mathematics teachers helps students understand mathematics concepts (Bingolbali, 2011). Those results agree with practising specific methods for solving mathematical problems. Students could learn a way of thinking to approach and solve problems successfully in a broader context in life (Szabo et al., 2020). The study by Darkis (2020) suggests that integrating technology in teaching is the best solution for effective teaching and learning of mathematics. Darkis proposes solutions to the problems for effective mathematics teaching, including Strengthen Mathematical Basis, attracting student interest, doing extra classes, and using the Easy-math model and cut-stop-solve model to effectively teach mathematical problem-solving.

Mathematics Challenging Topics Difficult to Teach

A Likert scale question with four levels of agreement (*very difficult = 1, difficult = 2, easy = 3, and very easy = 4*) was used to explore challenging mathematics topics difficult to teach. Before data collection, the researchers, in close collaboration with 15 ordinary and advanced level mathematics teachers from the Kayonza district, sit together and choose challenging mathematics topics. Among 40 challenging topics proposed to secondary school mathematics teachers. During the analysis, we combined very difficultly and difficult as a challenging topic while easy and very easy as a not difficult topic. From this rating, only 16 were selected as challenging topics difficult to teach in secondary schools. Quadratic equation, complex number, integral, Thale's theorem inverse and composite transformation, trigonometry, differentiation of polynomial, and the rational and irrational function were found to be at most challenging topics difficult to teach in secondary schools. Table 9.4 below shows a descriptive analysis of challenging mathematics topics difficult to teach.

From Table 9.4 above, during analysis, the mean of 1–2.9 was considered difficult while 3–4 was considered easy. The challenging mathematics topics identified were: collinear point and orthogonal vectors, point, line, and angles, solids, probability, logarithm, and exponential function, circle theorem, the limit of a polynomial, rational and irrational function, conics, sequences, Thale's theorem, integral, differentiation of polynomial, rational and irrational function, trigonometry, inverse and composite transformation, complex numbers, and quadratic equations.

Those results are in agreement with other authors. According to (Olubukola, 2015) found that trigonometry, arithmetic, geometry, probability, inequalities,

Table 9.2 Potential solution for teaching and learning materials of mathematics

Statements	N	Mean	Std. deviation
Use of web-based resources	109	2.5963	0.52914
Computer software	109	2.5596	0.51696
Manipulatives (e.g., ten base blocks, colour tiles, geometric solids	109	2.4495	0.60071
Use of calculator	109	2.3119	0.64832

Table 9.3 Potential solutions to effective teaching methods of mathematics

Statements	N	Mean	Std. deviation
Working in groups	109	2.6147	0.48892
Doing extra exercises	109	2.5742	0.5732
Practising	109	2.5688	0.64359
Presenting alternate methods of finding solutions	109	2.5413	0.50059
Class discussion	109	2.5046	0.58727
Problem-solving	109	2.4495	0.60071

Table 9.4 Descriptive analysis of challenging mathematic topics difficult to teach

Descriptive statistics			
Topics	N	Mean	Std. deviation
Collinear point and orthogonal vectors	109	2.3761	1.01643
Point, line, and angles	109	2.3211	0.76836
Solids	109	2.3211	1.06180
Probability	109	2.2936	1.01199
Logarithm and exponential function	109	2.2844	2.26524
Circle theorem	109	2.1468	0.88009
Limit of a polynomial, rational and irrational function	109	2.1009	0.91231
Conics	109	2.0550	0.95097
Sequences	109	2.0092	0.99532
Thale's theorem	109	1.9908	0.86598
Integral	109	1.9633	1.30474
Differentiation of polynomial, rational and irrational function	109	1.9541	0.82085
Trigonometry	109	1.9541	0.91677
Inverse and composite transformation	109	1.9174	0.90399
Complex numbers	109	1.7890	0.73375
Quadratic equation	109	1.7798	0.83175

numbers, and numeration are challenging topics to teach senior secondary school students. (Festus & Orobosa, 2013) showed circle and geometry theorem, Application of Trigonometry to the 2nd and 3rd Dimensional Problems, Drawing and making inferences from statistical diagrams, and Probability theorems as challenging topics difficult to teach in high school schools in Belize. The study by Batanero and Díaz (2012) highlighted probability as a challenging topic to teach in secondary schools. Batanero and Daiz proposed an action that teachers should consider, including teachers' collective analysis and discussion of the students' responses, behaviour, strategies, difficulties, and misconceptions when solving probability problems. Also, planning a lesson to teach students some content using a given instructional device to develop teachers' probability and professional knowledge of working with technology. Evidence from (Ibrahim & Ibrahim, 2018) indicates challenging topics in secondary schools, such as sequences and series, Quadratic Equations, Logarithms, Volumes, Circles, Linear Inequalities, and Angles

of elevation and depression. The research showed that integral is a difficult topic, and GeoGebra is an effective method to overcome difficulties.

Conclusion and Implication

Based on the finding and discussion of the study, the analysis showed that the abstractness nature of mathematics, time allocated and planning to mathematics, lack of CPD, curriculum changes, inadequate the technological tool, uninterested and negative peer influence of students, poor work habits, lack of teaching materials, lack of support from parents or guardian, too many contents and classroom size as challenges faced by mathematics teachers in their work. However, the study suggests potential solutions to overcome those challenges, such as using computer software, calculators, web-based resources, and manipulative tools in the teaching and learning materials category. In addition, use of problem-solving, class discussion, working in groups, Presenting alternate methods of finding solutions, practical work, and doing extra exercises in the category of teaching method. Furthermore, the study investigates challenging mathematic topics difficult to teach, which are: point, line and angles, solids, probability, Thale's theorem, quadratic equation, circle theorem, Collinear point, and orthogonal vectors, Inverse and composite transformation, trigonometry, Limit of polynomial, rational and irrational function integral, Differentiation of polynomial, rational and irrational function, sequences, logarithm and exponential function, complex number, and conics. Discussion results propose some teaching methods that can be used to teach highlighted challenging topics: project work, work with technology, doing extra exercises, discussion method, planning lessons, using the easy-maths model, and the cut-stop-solve model.

Based on the results, the study implies the following actions for effective mathematics teaching. Before starting a new topic, teachers should revise the previous content and give students more exercises that promote problem-solving skills. Teachers should also motivate their students to study mathematics and show them its application in everyday life. Teachers are also encouraged to integrate technology into their teaching because technology provides additional opportunities for learners to see and interact with mathematical concepts. The students are also encouraged to use their effort and explore more while studying as a method that will help them to succeed in mathematics. Students should change methods of learning during 4IR by embracing technology. Nowadays, in 4IR, where there is the rapid growth of technology, mathematics teachers and students are encouraged to join the platforms for teachers and students, such as web-based graphing calculators, Demos, and Mathspace. Teachers can also join online platforms for sharing, discussing, and testing mathematics concepts.

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