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Developing a Novel Model for ICT Integration in South African Education: Insights from TIMSS

Marien Alet Graham [1,*], Guillaume Matthys Kruger [2] and Linda van Ryneveld [3]

[1] Department of Early Childhood Education, University of Pretoria, Pretoria 0028, South Africa
[2] Department of Science, Mathematics and Technology Education, University of Pretoria, Pretoria 0028, South Africa
[3] Comprehensive Online Education Services, University of Pretoria, Pretoria 0028, South Africa; linda.vanryneveld@up.ac.za
* Correspondence: marien.graham@up.ac.za

Abstract: ICT integration in the classroom is viewed as a panacea towards resolving education challenges. A quantitative approach using South African Trends in International Mathematics and Science Studies (TIMSS) 2019 Grades 5&9 data with a positivist philosophical stance was used to explore ICT use. For a long time, most school research took the form of small-scale qualitative studies, such as case studies or critical policy studies; however, research in education has witnessed an increasing demand for high-quality, large-scale quantitative studies such as the current study. TIMSS utilised a two-stage stratified cluster sampling design, sampling schools by size and selecting intact classes. This study focusses on South Africa where 297 schools, 294 mathematics teachers, and 11,903 students were sampled at Grade 5 level, and, at Grade 9 level, the sample consisted of 519 schools, 543 mathematics teachers and 20,829 students. More than 50% of students attend schools lacking computers/tablets, a figure that rises to nearly 90% concerning their availability in classrooms. Less than half of students attend schools utilising online learning systems or providing digital resources. Principals in approximately half the schools indicated shortages/inadequacies in technologically competent staff, and audio-visual and computer technology/software resources. Approximately 80% of teachers expressed interest in future technology integration training for both grades when surveyed. Over half of the students lacked home internet access; however, the majority had access to cell phones and computers/tablets at home. In tailoring this study to the South African context, a novel model for ICT integration emerged which draws upon the Dynamic Model of Educational Effectiveness and the TIMSS curriculum model. Recommendations for improving policy and practice in ICT implementation in schools are structured around the new model.

Keywords: information communication technology; mathematics teaching and learning; TIMSS

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1. Introduction

Growing global apprehension surrounds the academic performance of South African mathematics students in schools. Initiatives such as the Trends in International Mathematics and Science Studies (TIMSS) aim to delve into various facets of mathematics achievement. TIMSS measures student performance at Grade 4 and Grade 8 level; however, South Africa participates at Grade 5 and Grade 9 levels due to its overall low performance in previous rounds of TIMSS [1]. Among the 64 countries participating in TIMSS 2019 at Grade 5 level, South Africa ranked amongst the lowest, with a score of 374, notably below the international benchmark of 500 points [2]. At Grade 9 level, among the 39 participating countries, South Africa ranked second to last with a score of 389 [3]. TIMSS sets a minimum benchmark of 400 points, indicating basic proficiency in mathematics. According to Reddy et al. [2,3], only 37% of South African Grade 5 students and 41% of South African Grade 9 students have reached this basic proficiency threshold, suggesting a substantial lack of fundamental mathematical knowledge for both grades. The concerning performance of South African students in mathematics underscores the urgent need for research into what can be improved within the South African educational system concerning mathematics teaching and learning (T&L). There is an expectation that integrating Information Communication Technologies (ICTs) into T&L will translate into better achievement of educational outcomes across schooling systems [4,5]. This research was initiated as a response to reports of significant expenditure on integrating ICT for T&L into South African schools [6]; however, evidence suggests that even investing substantial amounts into ICT integration in South African schools does not significantly improve student achievement [2,3]. This study hypothesizes that ICT investment has not improved student achievement because ICT has not been widely and effectively integrated into mathematics instruction. The research questions (RQs) are: RQ1: What ICTs are being used for mathematics T&L in South Africa? RQ2: Why are (or are not) certain ICTs being used for mathematics T&L in South Africa? RQ3: What models can be used to inform the implementation of effective ICT integration strategies within a South African context? Further investigation into the use of these ICTs in South African classrooms, and even outside the classrooms by the students, is paramount to discovering the problem areas, and, in this research, we used TIMSS 2019 data to explore this matter.

2. Literature Review

The present study builds on a literature foundation describing the benefits of ICT integration in the teaching and learning of mathematics. It also considers the extent to which technology has been made available in South African schools and how that technology has and has not been used. The review concludes with a conceptual framework.

2.1. Importance of ICT Integration in the T&L of Mathematics

Internationally, the benefits of integrating ICTs into the classroom have been empirically proven and established in recent research conducted in countries such as the United States [4], Italy [5], Israel [7], Indonesia [8] and Spain [9]. Engelbrecht and Borba [10] recently published an article on the new developments in using digital technology in mathematics education. In their article, they discuss various topics from redefined learning spaces (e.g., flipped classrooms where students are not introduced to new materials within mathematics lessons but, rather, are expected to work through materials before their lessons (usually made available online beforehand)), to the use of GeoGebra, student collaboration through virtual learning environments and social media, Artificial Intelligence (AI) and hyper-personalisation of learning, and multimodality (e.g., videos, virtual reality (VR), augmented reality (AR)). The authors highlight the benefits of all these new technologies but also list some concerns, such as the digital divide (some individuals (typically in low socio-economic areas) not having access to ICTs). The advantages of ICT integration in mathematics T&L have been documented by many authors (e.g., [10–12]); however, if one does not have access to technologies, how can one use them for the T&L of mathematics? Accordingly, the situation regarding technology diffusion in South African schools is considered next.

2.2. Technology Diffusion in South African Schools

Regarding technology diffusion, which in the context of the current study refers to the degree to which technology is present in South African schools, several national-level ICT initiatives have been implemented, such as the Teacher Laptop project, Sentech Ltd. and the Telkom Internet Project, which aimed to establish Supercentres in over 1300 schools equipped with computers, software, internet connections, and rent-free telephone lines. Initiatives like the eMindset Network and U-Tong portal have been launched to provide digital content resources via satellite television. eSchoolNet, South Africa's primary educator ICT development programme, aims to empower teachers to integrate ICT into the curriculum confidently. Furthermore, initiatives like Intel Teach to the Future and Microsoft

Partners in Learning offer training programmes covering basic ICT skills, ICT integration, peer coaching, and ICT leadership for education managers. Collaborations between the government and the private sector have led to projects like the Khanya Project and Gauteng Online, providing ICT-based resources in specific provinces. Ongoing national-level projects include the development of strategies from the integrated ICT policy review process, implementation of the SANReN (SANReN stands for "South African National Research Network"; see [13] for details) and TENET (TENET stands for "Tertiary Education and Research Network" of South Africa; see [13] for details), the "Broadcasting Digital Migration Policy for South Africa" (for more details on "Broadcasting Digital Migration Policy for South Africa", see [14]), and SA Connect (SA Connect is a "National wide government broadband connectivity project aimed at connecting government facilities" [15] (para. 1]) [16]. Despite all these initiatives, recent research in South African schools still reports that many South African schools do not have the necessary ICTs; for example, in the recent study by Mokotjo and Mokhele [17] on the challenges of integrating GeoGebra in the T&L of mathematics in South African secondary schools, they reported that there were insufficient resources in the schools (mostly due to security issues—schools being robbed and vandalized), causing teachers to become demotivated and disadvantaging students' learning of mathematics.

South Africa is categorised as an upper–middle–income country with high levels of compulsory school enrollment and significantly higher annual government expenditure on education compared to many other nations [6]. The World Bank [6] provides a notable example: In Sri Lanka, a lower–middle–income country, the average expenditure per primary school-aged child from 2015 to 2019 was approximately PPP$615; PPP stands for purchasing power parity. Despite this comparatively modest investment, Sri Lanka achieved remarkable results, with a learning poverty rate of only 15%. In stark contrast, South Africa allocated nearly PPP$2400 per primary school-aged child during a similar timeframe. However, the learning poverty rate in South Africa stood at a staggering 79%. This figure is akin to that of much poorer Guinea, where the expenditure per child was a mere PPP$144. Thus, despite significant investment in education, South Africa's outcomes are extremely poor, and many students lack basic mathematics skills [2,3]. Accordingly, ICT use, inside and outside the classroom, by teachers and South African students, at primary and secondary levels, warrants investigation. While the majority of studies have focused on the secondary level, investigating ICT use at the primary school level is essential. Acquiring basic ICT skills at a young age lays the foundation for more advanced ICT literacy skills later in life. These competencies equip young people for future technological use and critical reasoning. Accordingly, the next section considers the uses of ICT in South African mathematics T&L at primary and secondary levels.

2.3. Uses of ICT in South African Mathematics T&L

In South Africa, studies involving primary schools are considered first, followed by studies in secondary schools. Mwapwele and colleagues [18] analysed the baseline data from the ICT4E initiative (ICT4E stands for "Information and Communications Technology for Education"; see [19] for more detail), which encompassed data from 197 teachers from 24 primary and secondary rural schools across seven of the nine provinces of South Africa. They found that, despite some financial, technical, and digital skills challenges at their schools, teachers were optimistic about the advantages that ICT integration into T&L could bring. Mahwai and Wotela [19] also used the ICT4E project data, but only those of rural schools in Seshego Circuit, and concluded that the promise of successful ICT integration through this project was unsuccessful as the aims and objectives of the ICT4E project had not been achieved. In the same year, Dlamini [20] published the results of a large quantitative study (837 respondents from 133 schools) undertaken in Gauteng and concluded that teachers' limited technological pedagogical knowledge and limited experience in integrating computers into the classroom has had a negative impact on ICT uptake; they used the analytical framework of the Second Information Technology in Education Study

(SITES) in their investigation. Ramafi [21] analysed the data from 59 questionnaires and five interviews collected from public school teachers and identified six factors influencing ICT use: (i) government support, (ii) security measures provided for the ICT tools, (iii) teacher efficacy, (iv) learner efficacy, (v) state of ICT tools, (vi) and the use of ICT tools. Graham and colleagues [22] explored the reasons behind why (or why not) South African primary and secondary school teachers integrate ICTs in their classrooms using the UTAUT as a theoretical lens. They concluded that teachers only viewed technology integration as beneficial when it increased productivity and social influence. Using the same data set, these authors published a quantitative study one year later that investigated which ICTs were being used most in South African mathematics classrooms [23]. The researchers discovered that laptops/computers were the most frequently utilised ICT, with data projectors following as the next most frequently utilised ICT. They advised that professional development initiatives should prioritise instructing teachers on how to incorporate ICTs into their classrooms in a way that requires fundamental pedagogical adjustments.

Some examples of studies that only considered the secondary school level in South Africa are considered next. Ojo and Adu [24] conducted a study in the Eastern Cape Province using self-developed questionnaires and data from 450 students and 150 teachers. It was determined that the most abundant ICT resources in every chosen school were mobile phones, and these were utilised by pupils to exchange ideas and information regarding their courses and download pertinent information. Chisango and colleagues [25] adopted a qualitative research approach to explore rural secondary school teachers' perceptions of the use of ICTs in T&L and found that although teachers had a positive attitude towards the adoption of ICTs and were ready to integrate ICTs in T&L, they lacked the requisite ICT skills. Filita and Jita [26] conducted a study on teachers' perspectives on ICT integration in the teaching of Sesotho (one of South Africa's official languages) by conducting interviews, using the Technological Pedagogical Content Knowledge (TPACK) framework, and concluded that teachers lacked technological knowledge, and that the lack of Sesotho content in ICT resources negatively affected ICT adoption. More recently, Zenda and Dlamini [27] examined the factors that influence teachers' adoption of ICTs in rural secondary schools using a survey and found that having ICT infrastructure and a training policy in place were some of the reasons why teachers adopted ICTs in T&L; the modified UTAUT was used to guide this investigation. In 2024, Mnisi and colleagues [28] conducted a study in Gauteng using interviews and open-ended questionnaires with ten teachers and one curriculum specialist, and concluded that most schools are improving ICT use, but the biggest factor still hindering ICT integration is a lack of internet access in classrooms, hindering teachers from making full use of ICTs.

Some examples of studies that only considered the primary school level in South Africa are considered next. Saal and colleagues [29,30] used Grade 5 TIMSS 2015 data to explore the use of ICT in T&L in mathematics and found that almost 90% of South African students were taught by teachers who did not even have computers in their mathematics classrooms. This is a devasting finding, because they also found students who were in mathematical classes with computers significantly outperformed those without computers available to them. These same authors published a qualitative case study at primary school level, using the UTAUT (UTAUT stands for "Unified Theory of Acceptance and Use of Technology"; see [31] for more details) as a theoretical lens, to investigate the elements facilitating and hindering the integration of educational technology in mathematics education in economically disadvantaged areas of South Africa, and found that facilitating conditions (such as adequate technological infrastructure and qualified information technology technicians), and social influence (such as other teachers using ICTs in their classrooms) had the greatest impact on actual ICT use in the classroom of all the UTAUT constructs [32]; the interested reader is referred to Saal and colleagues [32] for more details on the UTAUT. Kolobe and Mihai [33] conducted an investigation into how ICTs are used as an intervention tool for progressed learners in T&L of English First Additional Language in Gauteng and concluded that ICTs had the potential to reduce failure rates, minimizing the number of learners who need to be progressed without meeting promotional requirements; the TPACK was used as theoretical framework. In a more recent study, Mahlo and Waghid [34] explored ICT integration among teaching in township public primary schools using lesson observations and interviews and concluded that the influence of personal conversion factors (ICT skills obtained through a community of practice and university training), had created the capabilities for teachers to use ICTs for T&L purposes, although to a limited extent.

The above literature review considered RQ1: What ICTs are being used for mathematics T&L in South Africa? RQ2: Why are (or are not) certain ICTs being used for mathematics T&L in South Africa? RQ3: What models can be used to inform the implementation of effective ICT integration strategies within a South African context? For RQ1 and RQ2, studies from many researchers were considered on what ICTs are being used, why they are (or are not) used (the latter speaking to ICT integration challenges and barriers), whereas, for RQ3, some of the frameworks and models used to inform effective integration were mentioned (e.g., TPACK, UTAUT, SITES framework). Moreover, regarding RQ3, some current studies purely focus on formulating ICT integration frameworks that are effective within a South African context; for example, ref. [35] formulated an ICT integration framework (described by the authors as an extension of the Technology Acceptance Framework [TAM]), responsive to the challenges that led to low ICT integration and more effective ICT integration in Gauteng schools. The literature points to the questions being posed in the current study as to what, why (or why not) ICTs are being used and what models can be used to inform ICT integration in South African schools as topical research.

2.4. Conceptual Framework: Towards a Model for the Integration of ICT in School

In tailoring this study to the South African context, an adaptation of the Dynamic Model of Educational Effectiveness (DMEE) was utilised as the foundational conceptual framework [36]. (The DMEE's contextual factors were redefined to incorporate South African-specific educational policies and ICT provisions, which differ significantly from the original model's European context. We tailored the school-level factors to reflect the distinct challenges related to technology integration faced by South African schools, such as limited access to digital resources and a lack of technologically competent staff. Classroom-level factors were adjusted to account for the varied levels of ICT availability in South African classrooms and the impact of this on teaching and learning practices. The student-level factors were revised to consider the external influences affecting South African students, such as socioeconomic barriers to technology access at home) This choice was made because the delineated levels of educational effectiveness within the DMEE align closely with the categories outlined in the TIMSS curriculum model [37]. The DMEE endeavours to delineate the factors correlated with educational effectiveness across four interconnected levels: context-related factors (e.g., national and regional educational policies), school-related factors (e.g., teaching and learning policies within schools), factors pertinent to the classroom and educators, and those related to students themselves [38]. This framework, illustrated in Figure 1, elucidates the interconnectedness of the DMEE, demonstrating how each level exerts either a direct or indirect influence on the others within the model.

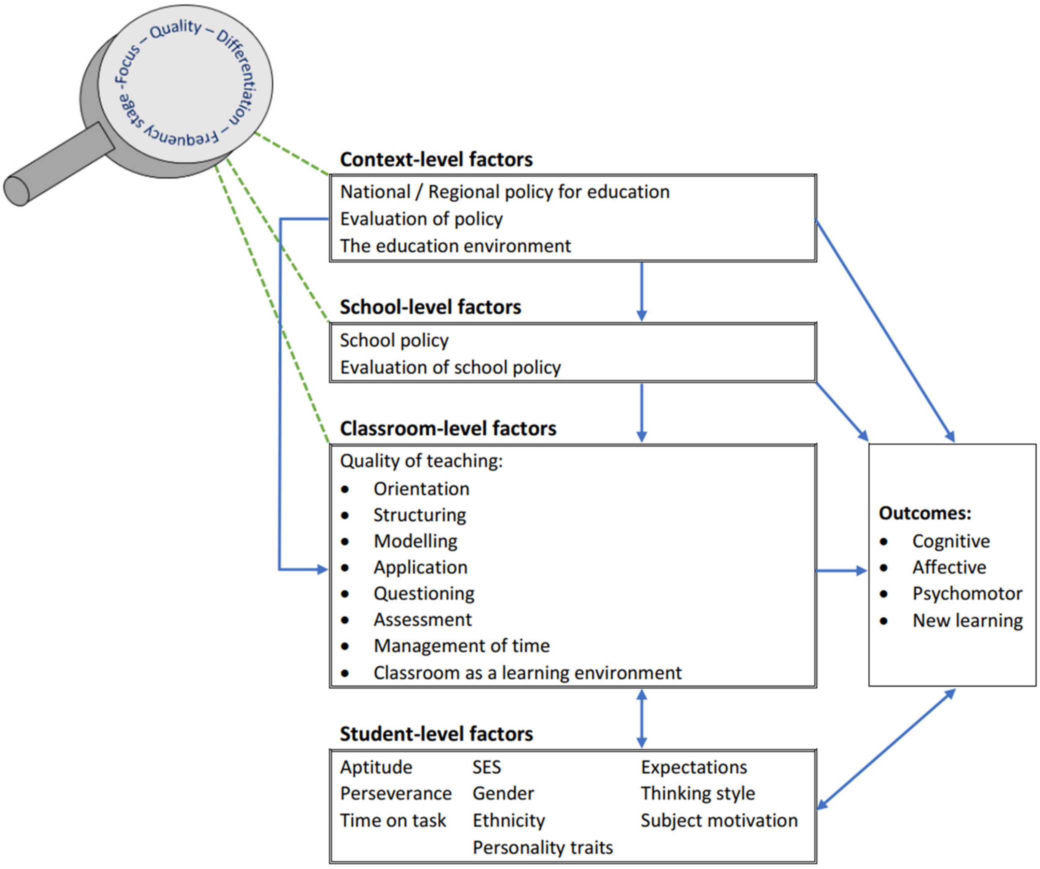

Figure 1. The DMEE [39], pp. 77, 150.

Upon reviewing the DMEE [36] alongside the IEA guidelines for researchers utilizing TIMSS data [40], it became evident that this study must also integrate the research areas outlined by the IEA when analyzing the TIMSS 2019 data. TIMSS studies are structured around a curriculum model that emphasises three key dimensions of teaching and learning: the intended curriculum, the implemented curriculum, and the attained curriculum [37], as depicted in Figure 2. This curriculum model serves as the cornerstone of TIMSS investigations and harmonises effectively with the levels of educational effectiveness delineated in the DMEE.

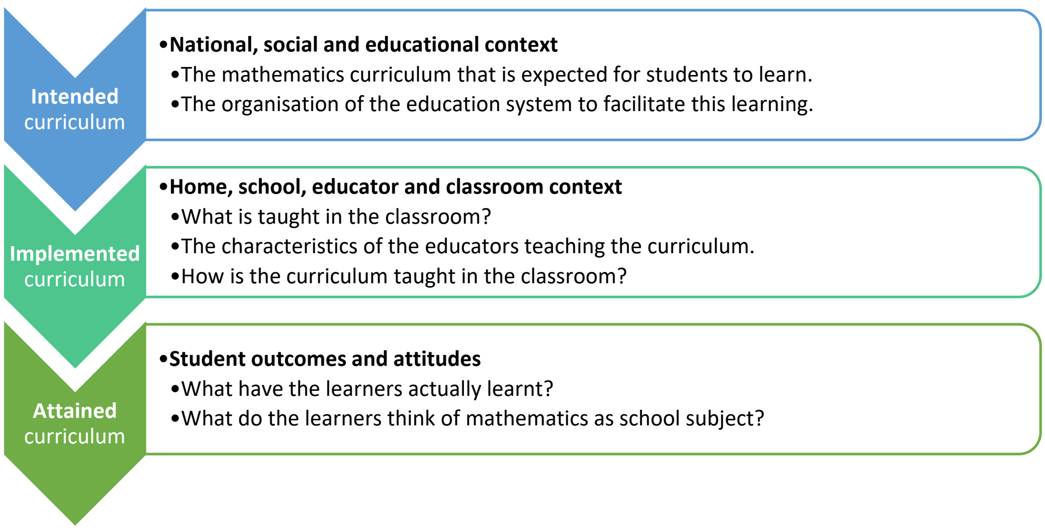

Figure 2. The TIMSS curriculum model. Note. Adapted from TIMSS framework of intended implemented and attained curriculum. Image, by [41]. CC BY-SA 4.0.

There are four distinct areas of research on which the TIMSS context questionnaires focus [42] and they are depicted in Table 1.

Table 1. TIMSS context questionnaires research areas.

TIMSS Context Questionnaire	Areas of Research
Mathematics curriculum questionnaire Country context	The mathematics curriculum as established by the Department of Education of the participating country.
ScQ School context	The educational environment in which both the student and instructor operate; this consists of elements like resource accessibility, the perception of safety on campus, and the support received from school administration.
TQ Educator and classroom context	The educator's background and the impact they have on the efficacy of teaching and learning in the classroom are factors to consider. This encompasses the educator's teaching methods, the practical implementation of acquired knowledge, and their educational credentials.
HQ Home context	Details concerning educational resources available at home, perspectives on the parents' highest level of education and employment circumstances, evaluations of their child's school, attendance record in preprimary education programmes, prioritisation of literacy and numeracy activities at home, and the parents' literacy and numeracy proficiency at the start of the academic year are all pertinent information.
StQ Student context	Student-specific information, including student-related context such as the student's home environment, academic motivation and application, and parental background and support availability, is encompassed within this category.

The relationship between the DMEE, the TIMSS curriculum model and the TIMSS context questionnaires is depicted in Table 2.

Table 2. Relationship between the DMEE, the TIMSS curriculum model and the TIMSS context questionnaires and assessment.

DMEE	TIMSS Curriculum Model	TIMSS Context Questionnaires and Assessment
Context-level factors (country and region)	Intended curriculum	Mathematics curriculum—Mathematics Curriculum Questionnaire
School-level factors	Implemented curriculum	School context—ScQ
Classroom-level factors	Implemented curriculum	Classroom and educator context—TQ
Home-level factors	Implemented curriculum	Home context—HQ
Student-level factors	Attained curriculum	Student achievement in TIMSS –Mathematics assessment Student context and background—StQ

While South African schools adhere to the uniform mathematics curriculum known as CAPS [43], the approach to implementation and the contextual factors vary greatly among schools nationwide. Given the diverse demographics of both schools and students, a simplistic perspective on mathematics achievement would be inadequate. Moreover, schools and students are embedded within social contexts, necessitating an examination of TIMSS results within broader community frameworks. The conceptual framework of this study aims to integrate these complex considerations, as illustrated in Figure 3.

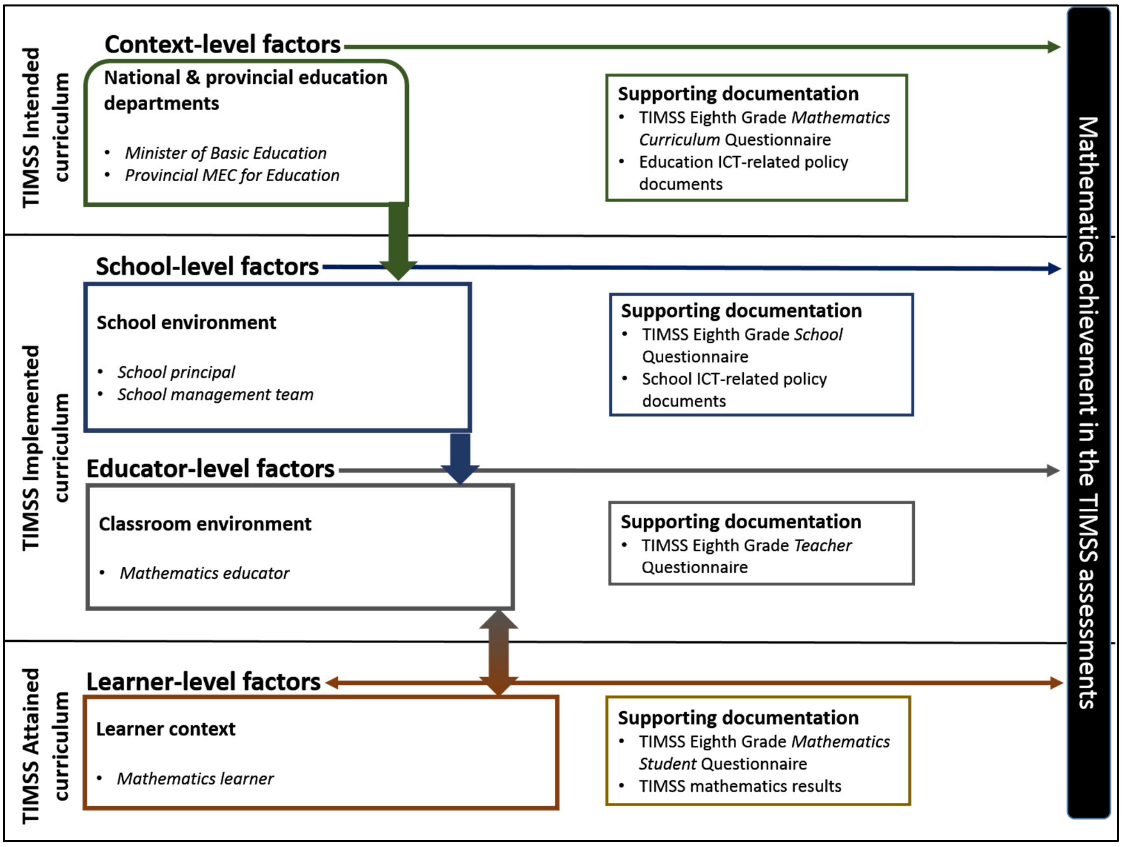

Figure 3. Conceptual framework of this study as adapted from [37,39].

3. Methodology

3.1. Research Approach and Design

A quantitative approach was followed with a positivist philosophical stance that relied on measurement and reason, and that knowledge was revealed from neutral and measurable (quantifiable) observations. Positivism builds on verifying a-priori hypotheses and experimentation by operationalizing variables and measures [44]. This study hypothesised that ICT investment has not improved South African students' mathematics achievement because ICT has not been widely and effectively integrated into mathematics instruction and, using the variables listed in Tables 3 and 4 in Section 4, we aimed to verify this a-priori hypothesis. The research design is a secondary data analysis [45], as this study used secondary data from TIMSS 2019. TIMSS data are cross-sectional in nature and not longitudinal, as TIMSS analyse data from different participants each cycle, i.e., they do not follow the same group of individuals over time [46]. As the focus of the current study is on South Africa, a purposive sampling technique [47] from within TIMSS 2019 was used by only selecting and working with the South African TIMSS 2019 mathematics data.

3.2. Participants

For South Africa, at Grade 5 level, the realised sample was 297 schools, 294 mathematics teachers, and 11,903 students [2]; whereas, at Grade 9 level, the sample consisted of 519 schools, 543 mathematics teachers, and 20,829 students [3]. The TIMSS 2019 employed a two-stage stratified cluster sampling methodology. In the first stage, schools were selected based on their size. In the second stage, one or more intact classes from the grade level of interest from each school that participated were chosen [48].

3.3. Instruments and Quality Assurance

TIMSS 2019 included a series of context surveys for various stakeholders, which were used in the present study to investigate the research questions [42]. Specifically, the principals answered a school questionnaire (ScQ), the teachers answered a teacher questionnaire (TQ), and the students answered the student questionnaire (StQ). Selected items from these context questionnaires relating to ICTs were analysed, and the items are displayed in Tables 3 and 4 in Section 4. All three authors of the manuscript analysed the context questionnaires, reaching a consensus on which items to use, specifically those related to ICT use. It should be noted that the selected questions are predominantly inventory-type (e.g., the number of computers available in the schools) and frequency–of–use questions (e.g., how often ICTs are used in class), rather than attitude-type questions. However, there are some opinion-based questions; for example, principals were asked to indicate how much the school's capacity to provide instruction is affected by a shortage or inadequacy of ICTs. This question is not purely inventory-type (i.e., whether the ICT is available or not), but rather relies on the subjective opinions of principals regarding the negative impact of potential ICT shortages. These questionnaires were designed within the framework of the TIMSS curriculum model [37]. In terms of quality assurance, TIMSS 2019 implemented various measures to ensure the reliability and validity of the assessment [48,49].

3.4. Data Analysis

The IEA IDB analyzer was used, supported by SPSS, to conduct the statistical analyses, which included descriptive statistics such as percentages, measures of location (mean, median), and measures of spread (standard deviation, interquartile range). Questions were analysed from the ScQ, TQ, and StQ. All variables that were considered, and their responses at Grade 5 and Grade 9 level, are shown in Tables 3 and 4 of Section 4. Multiple imputation was used to address missing values because it is widely regarded as the most valid method of addressing missingness, even when the data are not missing at random [50]. A last note is, when interpreting the results, it is important to note that, in TIMSS studies, the student is the unit of analysis; thus, say we interpret the responses of the principals (ScQ), it would be interpreted as the percentage of students attending the school, and not the number of principals—the same applies to the TQ answered by the teachers.

4. Results

Tables 3 and 4 display the TIMSS variables considered in the study, along with the responses at both Grade 5 and Grade 9 level, respectively. Table 3 shows the variables relating to RQ1: What ICTs are being used for mathematics T&L in South Africa?, whereas Table 4 shows the variables relating to RQ2: Why are (or are not) certain ICTs being used for mathematics T&L in South Africa? In Tables 3 and 4, variables with four response options were simplified to two response options for easier interpretation. The downward arrow ↘ indicates the grouping of the first two response options into one category, while the upward arrow ↗ indicates the grouping of the last two response options into another category.

Table 3. The TIMSS questions, variable names, and responses relating to RQ1.

TIMSS Question and Variable Name		Grade 5			Grade 9		
TQ (Grade 5: Answered by 294 Mathematics Teachers; Grade 9: Answered by 543 Mathematics Teachers)							
"If yes to having access to a computer or tablet in class, how often do you do activities on computers during mathematics lessons to support learning for":	"Whole class" Grade 5: ATBM04CA Grade 9: BTBM17CA	"Never or almost never" (17.6%) "Once or twice a month" (34.1%) "Once or twice a week" (48.3%) "Every or almost every day" (0.0%)	↘ ↗ ↘ ↗	Never to 1–2 pm (51.7%) 1–2 pw to always (48.3%)	"Never or almost never" (48.4%) "Once or twice a month" (24.9%) "Once or twice a week" (18.4%) "Every or almost every day" (7.9%)	↘ ↗ ↘ ↗	Never to 1–2 pm (73.7%) 1–2 pw to always (26.3%)

Table 3. *Cont.*

TIMSS Question and Variable Name		Grade 5			Grade 9		
"If yes to having access to a computer or tablet in class, how often do you do activities on computers during mathematics lessons to support learning for":	"Low-performing students" Grade 5: ATBM04CB Grade 9: BTBM17CB	"Never or almost never" (29.8%) "Once or twice a month" (31.0%) "Once or twice a week" (36.3%) "Every or almost every day" (2.9%)	↘ ↗ ↘ ↗	Never to 1–2 pm (60.8%) 1–2 pw to always (39.2%)	"Never or almost never" (56.3%) "Once or twice a month" (23.8%) "Once or twice a week" (7.7%) "Every or almost every day" (12.2%)	↘ ↗ ↘ ↗	Never to 1–2 pm (80.1%) 1–2 pw to always (19.9%)
	"High-performing students" Grade 5: ATBM04CC Grade 9: BTBM17CC	"Never or almost never" (28.4%) "Once or twice a month (21.7%) "Once or twice a week" (44.6%) "Every or almost every day" (5.3%)	↘ ↗ ↘ ↗	Never to 1–2 pm (50.1%) 1–2 pw to always (49.9%)	"Never or almost never" (52.6%) "Once or twice a month" (25.0%) "Once or twice a week" (14.4%) "Every or almost every day" (8.1%)	↘ ↗ ↘ ↗	Never to 1–2 pm (77.5%) 1–2 pw to always (22.5%)
	"Students with special needs" Grade 5: ATBM04CD Grade 9: BTBM17CD	"Never or almost never" (38.2%) "Once or twice a month" (22.6%) "Once or twice a week" (31.0%) "Every or almost every day" (8.2%)	↘ ↗ ↘ ↗	Never to 1–2 pm (60.8%) 1–2 pw to always (39.2%)	"Never or almost never" (57.0%) "Once or twice a month" (20.9%) "Once or twice a week" (12.6%) "Every or almost every day" (9.5%)	↘ ↗ ↘ ↗	Never to 1–2 pm (77.9%) 1–2 pw to always (22.1%)

Note: Never to 1–2 pm = Never to once or twice per month; 1–2 pw to always = Once to twice per week to always. All direct quotes are from the TIMSS questionnaires [51,52].

Table 1 shows the variables related to RQ1: What ICTs are being used for mathematics T&L in South Africa? Teachers (using TQ) reported using computers or tablets for T&L for the whole class more at Grade 5 level (approximately half reported using it "1–2 pw to always") as opposed to Grade 9 level where only about a quarter reported using it "1–2 pw to always". In Section 3.4, we noted that the student is the unit of analysis, so it is more accurate to say that, for Grade 5, almost half of the students attended classes where the teacher used computers or tablets one or two times per week to always. In contrast, only about a quarter of Grade 9 students were taught in classes where this occurred one or two times per week to always. Using computers and tablets for low-performing students again showed a higher percentage of use at Grade 5 level than Grade 9, and a similar pattern is seen when they reported on the use for high-performing students. When asked about the use of computers and tablets for students with special needs, again, the Grade 5 percentage was higher (approximately 40%) when reporting using it "1–2 pw to always" compared to Grade 9 teachers (approximately 20%).

Table 4. The TIMSS questions, variable names and responses relating to RQ2.

TIMSS Question and Variable Name	Grade 5	Grade 9
ScQ (Grade 5: Answered by 297 Principals; Grade 9: Answered by 519 Principals)		
"How many computers (including tablets and iPads) does your school have for use by Grade 5/9 students?" Grade 5: ACBG07 Grade 9: BCBG07	Mean = 12.26 SD = 20.42 Median = 0.00 * Interquartile range = 20.00	Mean = 21.79 SD = 42.45 Median = 0.00 ** Interquartile range = 30.00
"Does your school use an online learning management system to support learning (e.g., educator –student communication, management of grades, student access to course materials)?" Grade 5: ACBG09 Grade 9: BCBG09	Yes (12.6%) No (87.4%)	Yes (25.5%) No (74.5%)
"Does your school provide students with access to digital learning resources (e.g., books, videos)?" Grade 5: ACBG12 Grade 9: BCBG12	Yes (39.9%) No (60.1%)	Yes (49.7%) No (50.3%)

Table 4. *Cont.*

TIMSS Question and Variable Name		Grade 5		Grade 9	
"How much is your school's capacity to provide instruction affected by a shortage or inadequacy of":	"Technologically competent staff" Grade 5: ACBG13AF Grade 9: BCBG13AF	"Not at all" (13.0%) "A little" (27.6%) "Some" (40.7%) "A lot" (18.7%)	None to a little (40.6%) Some to a lot (59.4%)	"Not at all" (13.8%) "A little" (32.1%) "Some" (38.8%) "A lot" (15.2%)	None to a little (46.0%) Some to a lot (54.0%)
	"Audiovisual resources for delivery of instruction (e.g., interactive white boards, digital projectors)" Grade 5: ACBG13AG Grade 9: BCBG13AG	"Not at all" (29.7%) "A little" (20.5%) "Some" (16.3%) "A lot" (33.5%)	None to a little (50.2%) Some to a lot (49.8%)	"Not at all" (20.8%) "A little" (27.4%) "Some" (29.7%) "A lot" (22.1%)	None to a little (48.2%) Some to a lot (51.8%)
	"Computer technology for teaching and learning (e.g., computers or tablets for student use)" Grade 5: ACBG13AH Grade 9: BCBG13AH	"Not at all" (29.7%) "A little" (19.5%) "Some" (14.0%) "A lot" (36.8%)	None to a little (49.2%) Some to a lot (50.8%)	"Not at all" (25.9%) "A little" (24.7%) "Some" (25.4%) "A lot" (24.0%)	None to a little (50.6%) Some to a lot (49.4%)
	"Computer software/applications for mathematics instruction" Grade 5: ACBG13BB Grade 9: BCBG13BB	"Not at all" (29.0%) "A little" (24.1%) "Some" (18.8%) "A lot" (28.1%)	None to a little (53.1%) Some to a lot (46.9%)	"Not at all" (25.2%) "A little" (25.5%) "Some" (29.0%) "A lot" (20.2%)	None to a little (50.8%) Some to a lot (49.2%)
TQ (Grade 5: answered by 294 mathematics teachers; Grade 9: answered by 543 mathematics teachers)					
"Students in this class have computers (including tablets) available to use during their mathematics lessons," Grade 5: ATBM04A Grade 9: BTBM17A		Yes (9.1%) No (90.9%)		Yes (12.3%) No (87.7%)	
"If yes to having access to a computer or tablet in class, what access do they have":	"Each student has a computer" Grade 5: ATBM04BA Grade 9: BTBM17BA	Yes (4.5%) No (95.5%)		Yes (21.3%) No (78.7%)	
	"The class has computers that students can share" Grade 5: ATBM04BB Grade 9: BTBM17BB	Yes (38.3%) No (61.7%)		Yes (12.4%) No (87.6%)	
	"The school has computers that the class can use sometimes" Grade 5: ATBM04BC Grade 9: BTBM17BC	Yes (83.6%) No (16.4%)		Yes (53.7%) No (46.3%)	
"In the past two years, have you participated in professional development in integrating technology into mathematics instruction?" Grade 5: ATBM09AD Grade 9: BTBM22AD		Yes (44.8%) No (55.2%)		Yes (50.6%) No (49.4%)	
"Do you need future professional development in integrating technology into mathematics instruction?" Grade 5: ATBM09BD Grade 9: BTBM22BD		Yes (86.1%) No (13.9%)		Yes (85.0%) No (15.0%)	
StQ (Grade 5: answered by 22,903 students; Grade 9: answered by 20,829 students)					
"Do you have any of these things at your home?"	"A computer or tablet" Grade 5: ASBG05A Grade 9: BSBG05A	Yes (56.9%) No (43.1%)		Yes (52.2%) No (47.8%)	
	"Internet connection" Grade 5: ASBG05D Grade 9: BSBG05D	Yes (36.2%) No (63.8%)		Yes (43.0%) No (57.0%)	
	"Your own cell phone" Grade 5: ASBG05E Grade 9: BSBG05E	Yes (67.8%) No (32.2%)		Yes (79.1%) No (20.9%)	
	"Electricity" Grade 5: ASBG05G Grade 9: BSBG05G	Yes (83.5%) No (15.8%)		Yes (94.0%) No (6.0%)	

Note: Never to 1–2 pm = Never to once or twice per month; 1–2 pw to always = Once to twice per week to always. All direct quotes are from the TIMSS questionnaires [53–56]. * More than half (59.9%) of responses were zero. ** More than half (52.4%) of responses were zero.

Table 2 shows the variables relating to RQ2: Why are (or are not) certain ICTs being used for mathematics T&L in South Africa? Many of these questions are inventory-type questions about whether the ICTs are available in the first place, because a reason for not using ICTs could be not having access to them. There are also some questions about teacher professional development because if a teacher does not know how to use ICTs, they most probably will not use them. For school-level (TQ [Table 3] and ScQ [Table 4]), the ScQ will be considered first and it can be seen that the average number of computers (including tablets and iPads) available to Grade 5 students (mean = 12.26) is significantly lower than for Grade 9 students (mean = 21.79); however, the median is the same for both grades with the median of zero indicating that, for both Grade 5 and Grade 9, more than half of the responses were that there are zero computers available to students. Recall that, in Section 3.4, we mentioned that the student is the unit of analysis, so, using the percentages, the more accurate way of reporting these results would be to say that 59.9% of Grade 5 students attended classes where the principals reported there were no computers available to students, whereas this percentage is 52.4% for the Grade 9 learners. Regarding the use of online learning management systems to support learning, Grade 9 (25.5%) indicated higher usage compared to Grade 5 (12.6%). Recall that, in Section 3.4, we mentioned that the student is the unit of analysis, so the more accurate way of reporting these results would be to say that about one quarter of Grade 9 students attended class where the principals reported that the schools are using online learning management systems, compared to only 12.6% of Grade 5 students. When asked whether the school provides students with digital learning resources, almost 40% of Grade 5 students attended schools where this is the case, whereas, for Grade 9, this percentage was approximately 50%. When principals were questioned about how much their schools' capacity to provide instruction is affected by a shortage of different things related to technology, for both grades, the ratios were about 50–50 for all technology-related concepts (technologically competent staff, audio-visual and computer technology/software resources) indicating about a 50–50 split between them affecting instruction and not affecting instruction. Next, the responses to the TQ are considered. For Grade 5, approximately 90% of students attended mathematics lessons with no computers (including tablets) available in the mathematics classrooms, and this percentage was also approximately 90% for Grade 9. When asked whether teachers participated in professional development in integrating technology into mathematics instruction in the past two years, the responses were roughly 50–50 for both grades; however, this ratio changed dramatically when teachers were asked whether they would like to go for future professional development on this topic, where the ratio is approximately 20–80 for no–yes for both grades. For the student-level (StQ [Table 4]), for both grades, the majority of students had access to electricity at home. Regarding internet access at home, for both grades, more than half of the students indicated that they did not have it. When asked whether they owned a computer (or tablet) and their own cell phone, the percentage for cell phones was higher for both grades than for a computer/tablet, with all the percentage yes responses being above 50%, meaning more than half of Grade 5 and Grade 9 students had a computer/tablet and cell phone at home.

For RQ3, "What models can be used to inform the implementation of effective ICT integration strategies within a South African context?," there were no TIMSS questions that addressed this question; however, different models were considered in Section 2.1 using the available literature, and, during our study, a novel model for incorporating ICT into schools emerged, which are considered and discussed in detail in Sections 2.2 and 6.

5. Discussion

For RQ1, "What ICTs are being used for mathematics T&L in South Africa?", the results showed that computers and tablets were being used more often at Grade 5 level as opposed to Grade 9 level. These results could be attributed to the fact that many studies have shown the benefit of ICT integration in T&L for younger learners [57,58]. Unfortunately, the percentage use of other ICTs (e.g., interactive whiteboards) can not be discussed, as the TIMSS instruments do not go into that level of detail regarding ICT use.

For RQ2, "Why are (or are not) certain ICTs being used for mathematics T&L in South Africa?", the reasons seem to be three-fold. Many South African schools do not have access to ICTs (Reason 1), many students do not have access to ICTs at home (Reason 2), and teachers do not know how to integrate ICTs into T&L properly (Reason 3). Reason 1 was derived from the principals' responses for both Grade 5 and Grade 9, which made it evident that more than half of South African students are attending schools where there are no computers or tablets available. These results are concerning, given the substantial investment in ICT procurement, as they point to the fact that funds have not been fully utilised in their intended way which warrants investigation into how these funds were spent. When reporting on the use of online learning management systems to support learning and whether the school provided students with digital learning resources, very low percentages were reported by principals. Again, these low percentages, considering the financial investments made [6,16], are troubling. For Reason 2, although South African students have access to electricity at home, other ICT-related issues came to light; for example, regarding internet access at home, it is concerning that, for both grades, more than half of the students indicated that they do not have it. It should be noted that electricity was included in the analysis due to South Africa's ongoing electricity issues, which negatively affects the educational milieu [59]; one cannot use technology without electricity. For Reason 3, it came to light that many teachers expressed the desire to attend more professional development programmes on integrating ICTs in mathematics instruction and that approximately only half of teachers had undergone recent training in it. Similar results of South African teachers needing more professional development in ICT integration have been found by other researchers [22,28]. These conditions should be alarming to all stakeholders because they highlight significant gaps in the effective use of ICTs for mathematics teaching and learning.

For RQ3, "What models can be used to inform the implementation of effective ICT integration strategies within a South African context?," there were no relevant questions in the TIMSS dataset. However, various models and frameworks (e.g., TPACK, UTAUT, SITES framework) were reviewed in Section 2.1 based on the existing literature. Additionally, during our study, a new model for incorporating ICT into schools emerged, which draws upon the Dynamic Model of Educational Effectiveness and the TIMSS curriculum model. This novel model is thoroughly examined and discussed in Sections 2.2 and 6. We believe this model advances the theoretical framework for ICT integration in South African schools, as no single model has proven to be entirely effective. Organised around the Four Zones Model, recommendations emphasise the need for tailored support and continuous professional development at all levels of the education system. National and provincial education departments must provide substantial support and contextualised resources to schools, while school management should ensure equitable access to ICT resources and implement designated time slots for their use. Educators require targeted professional development programs focusing on fundamental computer literacy and practical aspects of ICT integration, while students should have access to high-quality educational software and equitable opportunities for engagement. By implementing these recommendations, South African schools can effectively harness the potential of ICT to enhance T&L outcomes, preparing students for success in a technology-driven society.

6. Improving the Integration of ICT in Schools to Show an Increased Educational Return on Investment

Upon analysing the research findings within the framework of this study, a novel model for incorporating ICT into schools emerged. This model draws upon the Dynamic Model of Educational Effectiveness (DMEE) by [36] and the TIMSS curriculum model [37]. Its objective is to guide the integration of ICT for T&L in schools by delineating distinct zones of impact, key stakeholders, and curriculum expectations throughout the ICT implementation process. This proposed model, termed the "Four Zones Model for the Integration of ICT in Schools" (Four Zones Model), is illustrated in Figure 4.

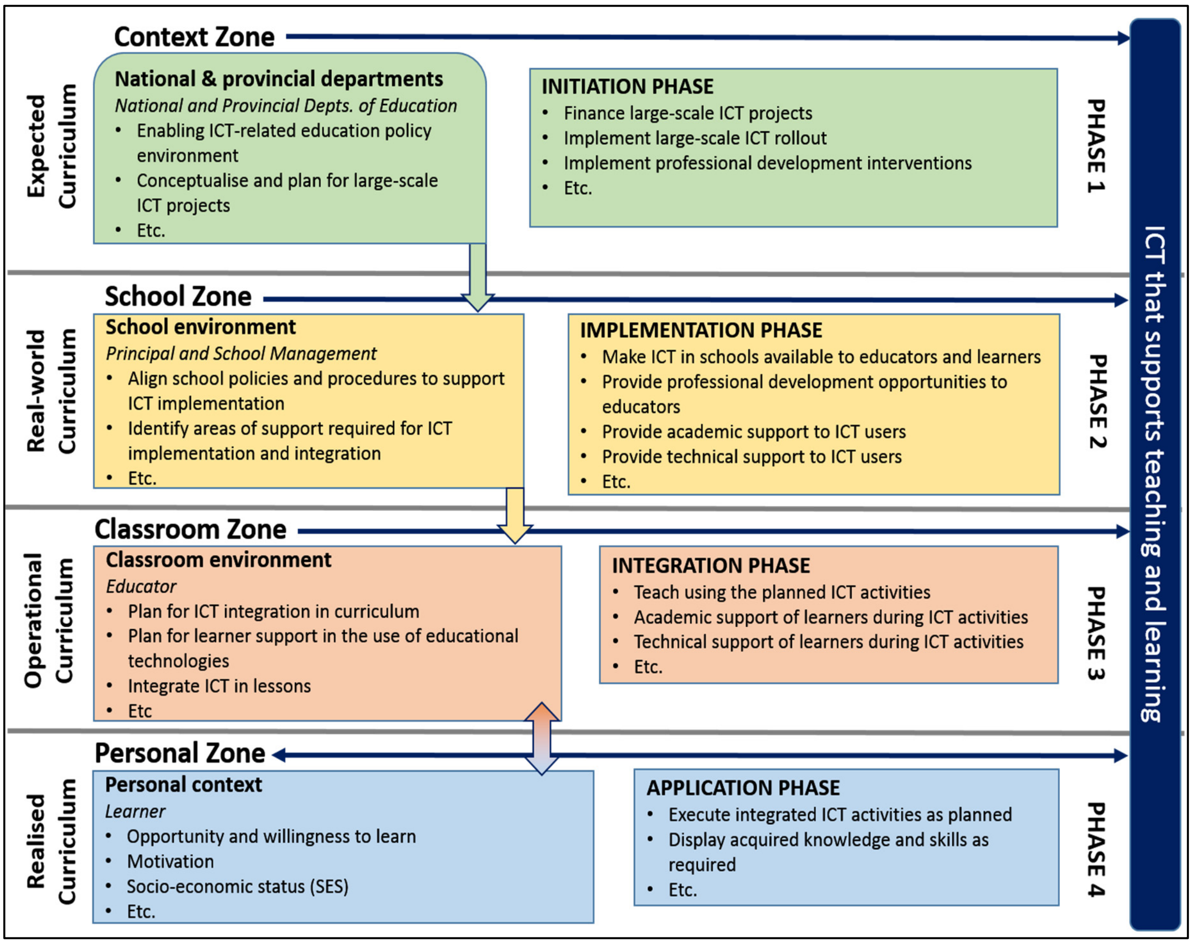

Figure 4. The Four Zones Model.

Structured around four zones of impact akin to those identified by Creemers and Kyriakides [39], the Four Zones Model comprises the Context Zone, School Zone, Classroom Zone, and Personal Zone. Each zone is associated with specific curriculum expectations mirroring those outlined in the TIMSS curriculum by the IEA [37], namely the Expected Curriculum, Real-world Curriculum, Operational Curriculum, and Realised Curriculum. Additionally, the model delineates phases essential for successful ICT integration in teaching and learning environments, as identified through an examination of the roles and responsibilities within each impact zone. ICT integration and implementation, outlined in the Four Zones Model, include the Initiation Phase, Implementation Phase, Integration Phase, and Application Phase.

The initial stage of the Four Zones Model is termed the Initiation Phase, situated within the Context Zone. This phase encompasses the functions and duties of national and provincial Departments of Education. These departments play a pivotal role in establishing a conducive policy and legal framework to facilitate the integration of ICT within schools. Given the limited financial resources of many schools to acquire ICT resources for educational purposes, this study underscores the imperative for Departments of Education to spearhead the distribution of ICT infrastructure to schools. Additionally, within the Context Zone lies the delineation of the Expected Curriculum, which embodies the official curriculum sanctioned by the Departments of Education.

The second stage in the Four Zones Model is termed the Implementation Phase, situated within the School Zone, delineating the responsibilities of school principals and management. Within this phase, school management holds the pivotal role of fostering an environment conducive to ICT integration through the formulation of school policies and protocols that facilitate its effective utilisation. Findings from this study suggest instances where, despite the presence of ICT infrastructure within schools, its integration into T&L processes remained limited. Many educators, despite undergoing professional development interventions, seemed unable to apply acquired knowledge in practice. Establishing an enabling environment for ICT integration may involve seemingly straightforward measures such as ensuring equitable access to computer facilities by scheduling dedicated time for each class. Moreover, school management bears the responsibility of arranging necessary support for ICT users, which could be as simple as assigning an enthusiastic staff member to oversee ICT assistance. Additionally, an often-overlooked necessity is the provision of additional time for educators to plan and implement ICT integration into their lessons. School management could address this need by recognising ICT planning and implementation as a designated extracurricular activity, allowing educators the requisite time. Within the School Zone, the Real-world Curriculum is outlined, reflecting the curriculum's implementation guided by school-specific policies, procedures, and supportive structures.

The third stage within the Four Zones Model, known as the Integration Phase, holds paramount significance as it marks the operationalisation of ICT integration. Nestled within the Classroom Zone, this phase delineates the duties and obligations of educators within their classrooms. The incorporation of ICT into the school curriculum represents a novel undertaking for most educational institutions, necessitating educators to revise their existing lesson plans to accommodate ICT integration seamlessly. Following the planning stage, educators assume the responsibility of delivering lessons utilising newly devised ICT activities. Moreover, educators are tasked with providing technical support to students encountering challenges while utilising ICT to fulfill assigned tasks. Findings from this study indicate that, although many educators exhibit enthusiasm towards ICT integration in T&L, and participate in professional development initiatives, such interventions often fall short in adequately preparing educators for the practical realities of integrating ICT into their pedagogical practices. Within the Classroom Zone, the Operational Curriculum is outlined, reflecting the curriculum as implemented by educators within the school setting.

The final stage in the Four Zones Model is the Application Phase, situated within the Personal Zone, elucidating the roles and obligations of students within and outside the classroom environment. With ICT integration, the dynamics of T&L shift from being centered on educators to becoming centered on students. Consequently, students are entrusted with the responsibility of taking charge of their own educational journey. Within the Personal Zone, the Realised Curriculum is delineated, representing the curriculum as grasped and achieved by students. It serves as the culmination of the Expected Curriculum, embodying the ultimate outcome of the educational process.

The Four Zones Model endeavours to address the prevalent issue of ambiguity surrounding the roles and responsibilities of various stakeholders involved in the integration of ICT within schools. While originally conceptualised within the context of South African education, the model possesses a level of generality that renders it adaptable to diverse educational settings beyond South Africa. Hence, it is recommended that the Four Zones Model be regarded as a guiding framework for forthcoming ICT integration projects within schools.

6.1. Reliability of the Four Zones Model

The researchers have engaged in discussions with domain experts in educational technology and policy-making to critique and refine the model. This expert feedback is being systematically incorporated to strengthen the model's consistency and application potential. A series of hypothetical applications of the model to past ICT integration projects are being undertaken. By examining how the model would have functioned in these well-documented instances, we aim to assess its reliability in various educational settings.

6.2. Validity of the Four Zones Model

We have more deeply grounded the model in the existing literature and theories of educational technology adoption, such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), to establish its face and content validity. The model has also been subjected to scrutiny by a panel of experts in ICT in education, who have provided insights and recommendations to ensure that it adequately represents the complex dynamics of ICT integration in schools.

7. Recommendations for Improved Implementation of ICT in Schools

Recommendations for improved policy and practice in the implementation of ICT in schools are organised according to the four zones of impact as identified in the proposed "Four Zones Model for the Integration of ICT in Schools". The zones identified are the Context Zone, the School Zone, the Classroom Zone and the Personal Zone.

7.1. The Context Zone (National and Provincial Departments of Education)

It is evident that schools require substantial support from both national and provincial education departments when implementing ICT hardware and software. The selection of educational software must be tailored to meet the specific educational needs of students in each school, rather than adopting a uniform solution for all schools within a province. Furthermore, contextualising educational software is essential to ensure that students can relate to the content, language, and assessment methods employed. For large-scale ICT projects in education, continuous technical and academic support should be provided to schools and educators to facilitate the seamless integration of educational software into regular classroom practices.

7.2. The School Zone (Principals and School Management)

According to the conclusions drawn from this study, it appears that school principals require distinct professional development initiatives for effectively integrating ICT into the school curriculum, differing from those tailored for educators. Many principals demonstrate a lack of clarity regarding their role in implementing ICT integration within the curriculum and struggle to recognise the potential positive impacts of ICT on T&L within their schools. Additionally, their leadership in promoting the integration and utilisation of ICT in T&L appears inadequate when they themselves lack a comprehensive understanding of ICT integration. Considering the substantial financial investment required for ICT implementation, it becomes imperative for school management to assume responsibility for the effective utilisation of ICT resources. It is incumbent upon school management to administer the school's ICT resources in a manner that ensures equitable access for all educators and classes. Implementing a weekly designated time slot within the formal school timetable could be a practical solution to ensure each class receives fair access to the school's ICT equipment.

7.3. The Classroom Zone (Educators)

Initiating professional development programs for educators concerning ICT integration within the school curriculum should commence with addressing fundamental computer literacy and skills. It is crucial for educators to feel at ease with computer usage for personal tasks, as lacking this confidence may impede their ability to effectively integrate ICT into their teaching practices. There is a pressing need to enhance opportunities for professional development among educators concerning ICT integration within the school curriculum. The observed number of educators who reported non-attendance at professional development activities underscores this urgency. Centralised management of these professional development initiatives by national or provincial education departments could ensure equitable access for all educators. Professional development interventions for educators must prioritise practical aspects of ICT integration within the school curriculum and incorporate workplace-based support.

7.4. The Personal Zone (Students)

Regular use of ICT is essential for students to cultivate non-academic skills essential for active engagement in the knowledge-driven society awaiting them beyond school. Nevertheless, many students lack access to computers at home, underscoring the responsibility of education departments and schools to provide access to computers and software during school hours. Educational software must be tailored to the educational level of students within each school, and students should have sufficient time allocated for engaging with high-quality educational software. The more time students spend with high-quality educational software, the greater the likelihood of meaningful learning and improved academic achievement. Thus, it is incumbent upon school management to ensure equitable access to ICT resources for all students within the school environment.

8. Limitations

A limitation of the current study is that a secondary data analysis was conducted. Conducting a secondary data analysis presents several limitations that researchers must consider. Firstly, the original data may not have been collected with the specific research questions in mind, leading to potential gaps in the dataset that may hinder comprehensive analysis. Additionally, the quality of the data may vary, as it relies on the accuracy and reliability of the original data collection methods and procedures. Researchers may encounter issues with missing or incomplete data, inconsistencies in data coding, or inaccuracies in measurements, all of which can compromise the reliability and validity of the findings. Furthermore, secondary data analysis may limit researchers' ability to control for confounding variables or explore alternative explanations for observed phenomena, as they have no control over the data collection process. These limitations were mitigated by thoroughly studying the TIMSS booklets and familiarising ourselves with all the steps and procedures followed by the TIMSS researchers.

9. Conclusions

While our study is grounded in the specific context of South African schools, the findings and implications carry broader significance for several reasons. The obstacles and successes identified in the South African context often mirror those in other emerging economies and even in under-resourced areas of developed countries. The strategies and models we propose can be informative for similar contexts where educational technology integration is a work in progress. Furthermore, the Four Zones Model, though developed within the South African framework, is designed with adaptability in mind. It is based on universal principles of ICT integration that are relevant to diverse educational settings. We anticipate that the model can be adjusted to suit different regional and cultural contexts. Finally, the trends and patterns in ICT use we have identified contribute to the global discourse on educational technology. Our research adds to the understanding of how ICT can influence educational outcomes, which is a subject of international concern.

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References

1. Reddy, V.; Zuze, T.L.; Visser, M.; Winnaar, L.; Juan, A.; Prinsloo, C.H.; Arends, F.; Rogers, S. *Beyond Benchmarks: What Twenty Years of TIMSS Data Tell Us about South African Education*; Human Sciences Research Council: Pretoria, South Africa, 2015.
2. Reddy, V.; Winnaar, L.; Juan, A.; Arends, F.; Harvey, J.; Hannan, S.; Namome, C.; Zulu, N. *TIMSS 2019 Highlights of South African Grade 5 Results in Mathematics and Science*; Department of Basic Education: Pretoria, South Africa, 2020.
3. Reddy, V.; Winnaar, L.; Juan, A.; Arends, F.; Harvey, J.; Hannan, S.; Namome, C.; Sekhejane, P.; Zulu, N. *TIMSS 2019: Highlights of South African Grade 9 Results in Mathematics and Science*; Department of Basic Education: Pretoria, South Africa, 2020.
4. Dahshan, M.; Galanti, T. Teachers in the loop: Integrating computational thinking and mathematics to build early place value understanding. *Educ. Sci.* **2024**, *14*, 201. [CrossRef]
5. Schiavo, F.; Campitiello, L.; Todino, M.D.; Di Tore, P.A. Educational robots, emotion recognition and ASD: New horizon in special education. *Educ. Sci.* **2024**, *14*, 258. [CrossRef]
6. World Bank. *The Adequacy of Public Expenditure on Education and the Needs Post-COVID-19*; World Bank Group: Bretton Woods, NH, USA, 2023.
7. Rayan, B.; Watted, A. Enhancing education in elementary schools through gamified learning: Exploring the impact of Kahoot! on the learning process. *Educ. Sci.* **2024**, *14*, 277. [CrossRef]
8. Rasdiana Wiyono, B.B.; Imron Al Rahma, L.; Arifah, N.; Azhari, R.; Elfira; Sibula, I.; Maharmawan, M.A. Elevating teachers' professional digital competence: Synergies of principals' instructional e-supervision, technology leadership and digital culture for educational excellence in digital-savvy era. *Educ. Sci.* **2024**, *14*, 266. [CrossRef]
9. Elecalde, R.G.; Garcia, J.C.; Martos AL, B.; Arnáez, B.S. Digital and social-civic skills in future primary education teachers: A study from the didactics of social sciences for the improvement of teacher training in competences. *Educ. Sci.* **2024**, *14*, 211. [CrossRef]
10. Engelbrecht, J.; Borba, M.C. Recent developments in using digital technology in mathematics education. *ZDM–Math. Educ.* **2023**, *56*, 281–292. [CrossRef]
11. Attard, C.; Holmes, K. *Technology-Enabled Mathematics Education: Optimising Student Engagement*; Routledge: London, UK, 2019.
12. Hansson, S.O. Technology and mathematics. *Philos. Technol.* **2020**, *33*, 117–139. [CrossRef]
13. South African National Research Network. The South African NREN. SANReN. 2024. Available online: https://www.sanren.ac.za/south-african-nren/ (accessed on 20 February 2024).
14. Department of Communications. *Broadcasting Digital Migration Policy for South Africa*; Republic of South Africa: Pretoria, South Africa, 2008.
15. Infrastructure South Africa. SA Connect. Republic of South Africa. 2022. Available online: https://infrastructuresa.org/sip-projects/sa-connect-phase-2/ (accessed on 10 December 2023).
16. Barakabitze, A.A.; Lazaro, A.W.-A.; Ainea, N.; Mkwizu, M.H.; Maziku, H.; Matofali, A.X.; Iddi, A.; Sanga, C. Transforming African education systems in science, technology, engineering, and mathematics (STEM) using ICTs: Challenges and opportunities. *Educ. Res. Int.* **2019**, *2019*, 6946809. [CrossRef]
17. Mokotjo, L.; Mokhele, M.L. Challenges of integrating GeoGebra in the teaching of mathematics in South African high schools. *Univers. J. Educ. Res.* **2021**, *9*, 963–973. [CrossRef]
18. Mwapwele, S.D.; Marais, M.; Dlamini, S.; Van Biljon, J. Teachers' ICT adoption in South African rural schools: A study of technology readiness and implications for the South Africa connect broadband policy. *Afr. J. Inf. Commun.* **2019**, *24*, 1–21.
19. Mahwai, N.J.; Wotela, K. Integrating technology in teaching and learning: Have Seshego Circuit rural schools escaped the challenges? *J. Public Adm. Dev. Altern.* **2022**, *7*, 55–67. [CrossRef]
20. Dlamini, R. Factors constraining teacher integration of ICT in Gauteng schools. *Indep. J. Teach. Learn.* **2022**, *17*, 28–43.
21. Ramafi, P. Investigating the barriers of ICT use in teaching and learning at public schools in South Africa. In Proceedings of the 2022 International Conference on Intelligent and Innovative Computing Applications, Balaclava, Mauritius, 8–9 December 2022; pp. 92–102. [CrossRef]
22. Graham, M.A.; Stols, G.; Kapp, R. Teacher practice and integration of ICT: Why are or aren't South African teachers using ICTs in their classrooms. *Int. J. Instr.* **2020**, *13*, 749–766. [CrossRef]
23. Graham, M.A.; Stols, G.H.; Kapp, R. Integrating classroom technology: South African mathematics teachers. *Comput. Sch.* **2021**, *38*, 189–213. [CrossRef]
24. Ojo, O.A.; Adu, E.O. The effectiveness of Information and Communication Technologies (ICTs) in teaching and learning in high schools in Eastern Cape Province. *S. Afr. J. Educ.* **2018**, *38*, 1483. [CrossRef]
25. Chisango, G.; Marongwe, N.; Mtsi, N.; Matyedi, T.E. Teachers' perceptions of adopting information and communication technologies in teaching and learning at rural secondary schools in eastern cape. *S. Africa. Afr. Educ. Rev.* **2020**, *17*, 1–19. [CrossRef]
26. Filita, N.; Jita, T. Teachers' perspectives on the use of ICT in the teaching of a South African home language, Sesotho. *J. Lang. Teach.* **2021**, *55*, 219–241. [CrossRef]
27. Zenda, R.; Dlamini, R. Examining factors that influence teachers to adopt information and communication technology in rural secondary schools: An empirical study. *Educ. Inf. Technol.* **2023**, *28*, 815–832. [CrossRef]
28. Mnisi, B.R.; Mtshali, T.I.; Moses, M. Moving beyond the challenges of learning through technologies: The current status of ICT integration in South African schools. *J. Educ. e-Learn. Res.* **2024**, *11*, 125–134. [CrossRef]

29. Saal, P.E.; Van Ryneveld, L.; Graham, M.A. The relationship between using information and communication technology in education at the mathematics achievement of students. *Int. J. Instr.* **2019**, *12*, 405–424. [CrossRef]
30. Saal, P.E.; Van Ryneveld, L.; Graham, M.A. Comparing the relationship between using educational technology in mathematics and student achievement in South Africa and Germany. *J. Res. Technol. Educ.* **2022**, *54*, 581–598. [CrossRef]
31. Venkatesh, V.; Morris, M.G.; Davis, G.B.; Davis, F.D. User acceptance of information technology: Toward a unified view. *MIS Q.* **2003**, *27*, 425–478. [CrossRef]
32. Saal, P.E.; Graham, M.A.; Van Ryneveld, L. Integrating educational technology in mathematics education in economically disadvantaged areas in South Africa. *Comput. Sch.* **2020**, *37*, 253–268. [CrossRef]
33. Kolobe, L.; Mihai, M. The integration of technology in supporting progressed learners in English First Additional Language comprehension. *Perspect. Educ.* **2021**, *39*, 303–323. [CrossRef]
34. Mahlo, L.; Waghid, Z. Exploring information and communication technology integration among teachers in township public primary schools. *S. Afr. J. Educ.* **2023**, *43*, 2160. [CrossRef]
35. Ntsobi, M.; Nyamkure, B. Responsive ICT integration framework to enhance teaching and learning in Gauteng schools. In Proceedings of the 2024 8th World Conference on Qualitative Research, Azores (Portugal), Johannesburg (South Africa), and online, 23–25 January 2024.
36. Creemers, B.P.; Kyriakides, L. School factors explaining achievement on cognitive and affective outcomes: Establishing a dynamic model of educational effectiveness. *Scand. J. Educ. Res.* **2010**, *54*, 263–294. [CrossRef]
37. Mullis, I.V.S. Introduction. In *TIMSS 2019 Assessment Frameworks*; Mullis, I.V.S., Martin, M.O., Eds.; Boston College, TIMSS & PIRLS International Study Center: Chestnut Hill, MA, USA, 2017; pp. 3–10. Available online: https://timssandpirls.bc.edu/timss2019/frameworks/framework-chapters/context-questionnaire-framework/ (accessed on 27 April 2024).
38. Antoniou, P.; Kyriakides, L.; Creemers, B.P.M. Investigating the effectiveness of a dynamic integrated approach to teacher professional development. *CEPS J. Cent. Educ. Policy Stud. J.* **2011**, *1*, 13–41. [CrossRef]
39. Creemers, B.P.; Kyriakides, L. *The Dynamics of Educational Effectiveness: A Contribution to Policy, Practice, and Theory in Contemporary Schools*; Routledge: London, UK, 2007.
40. Fishbein, B.; Foy, P.; Yin, L. *TIMSS 2019 User Guide for the International Database*, 2nd ed.; TIMSS & PIRLS International Study Center, Lynch School of Education, Boston College and International Association for the Evaluation of Educational Achievement: Chestnut Hill, MA, USA, 2021.
41. Hossain, M.Z. Implementation of Grade 8 science curriculum 2012 in Bangladesh: Challenges and way forward. *J. Educ. Res.* **2019**, *9*, 93–117. [CrossRef]
42. Hooper, M.; Mullis, I.V.S.; Martin, M.O.; Fishbein, B. TIMSS 2019 context questionnaire framework. In *TIMSS 2019 Assessment Frameworks*; Mullis, I.V.S., Martin, M.O., Eds.; Boston College, TIMSS & PIRLS International Study Center: Chestnut Hill, MA, USA, 2017; pp. 59–78. Available online: https://timssandpirls.bc.edu/timss2019/frameworks/framework-chapters/context-questionnaire-framework/ (accessed on 10 August 2020).
43. Department of Basic Education. *Curriculum Assessment Policy Statements (CAPS)*; Government Printers: Pretoria, South Africa, 2011.
44. Park, Y.S.; Konge, L.; Artino, A.R., Jr. The positivism paradigm of research. *Acad. Med.* **2020**, *95*, 690–694. [CrossRef]
45. Mouton, J. *How to Succeed in Your Master's and Doctoral Studies: A South African Guide and Resource Book*; Van Schaik: Pretoria, South Africa, 2001.
46. Wang, X.; Cheng, Z. Cross-sectional studies: Strengths, weaknesses, and recommendations. *Chest* **2020**, *158*, S65–S71. [CrossRef]
47. Andrade, C. The inconvenient truth about convenience and purposive samples. *Indian J. Psychol. Med.* **2021**, *43*, 86–88. [CrossRef]
48. LaRoche, S.; Joncas, M.; Foy, P. Sample design in TIMSS 2019. In *Methods and Procedures: TIMSS 2019 Technical Report*; Martin, M.O., von Davier, M., Mullis, I.V.S., Eds.; TIMSS & PIRLS International Study Center: Amsterdam, The Netherlands, 2020; pp. 51–83.
49. Cotter, K.E.; Centurino, V.A.S.; Mullis, I.V.S. Developing the TIMSS 2019 mathematics and science achievement instruments. In *Methods and Procedures: TIMSS 2019 Technical Report*; Martin, M.O., von Davier, M., Mullis, I.V.S., Eds.; TIMSS & PIRLS International Study Center: Amsterdam, The Netherlands, 2020; pp. 6–41.
50. Van Ginkel, J.R.; Linting, M.; Rippe, R.C.A.; Van der Voort, A. Rebutting existing misconceptions about multiple imputation as a method for handling missing data. *J. Personal. Assess.* **2020**, *102*, 297–308. [CrossRef] [PubMed]
51. Trends in International Mathematics and Science Study. Teacher Questionnaire: Grade 5. Boston College, TIMSS & PIRLS International Study Center. 2018. Available online: https://timssandpirls.bc.edu/timss2019/questionnaires/index.html (accessed on 10 August 2020).
52. Trends in International Mathematics and Science Study. Teacher Questionnaire: Grade 9. Boston College, TIMSS & PIRLS International Study Center. 2018. Available online: https://timssandpirls.bc.edu/timss2019/questionnaires/index.html (accessed on 10 August 2020).
53. Trends in International Mathematics and Science Study. School Questionnaire: Grade 5. Boston College, TIMSS & PIRLS International Study Center. 2018. Available online: https://timssandpirls.bc.edu/timss2019/questionnaires/index.html (accessed on 10 August 2020).

54. Trends in International Mathematics and Science Study. School Questionnaire: Grade 9. Boston College, TIMSS & PIRLS International Study Center. 2018. Available online: https://timssandpirls.bc.edu/timss2019/questionnaires/index.html (accessed on 10 August 2020).
55. Trends in International Mathematics and Science Study. Student Questionnaire: Grade 5. Boston College, TIMSS & PIRLS International Study Center. 2018. Available online: https://timssandpirls.bc.edu/timss2019/questionnaires/index.html (accessed on 10 August 2020).
56. Trends in International Mathematics and Science Study. Student Questionnaire: Grade 9. Boston College, TIMSS & PIRLS International Study Center. 2018. Available online: https://timssandpirls.bc.edu/timss2019/questionnaires/index.html (accessed on 10 August 2020).
57. Siew, P.H. Pedagogical change in mathematics learning: Harnessing the power of digital game-based learning. *Educ. Technol. Soc.* **2018**, *21*, 259–276.
58. Janković, A.; Maričić, M.; Cvjetićanin, S. Comparing science success of primary school students in the gamified learning environment via Kahoot and Quizizz. *J. Comput. Educ.* **2024**, *11*, 471–494. [CrossRef]
59. Pillay, N.S.; Okonkwo, C.W.; Anele, A. The impact of loadshedding on student academic performance: A data analytics approach. In Proceedings of the 2023 International Conference of Teaching, Assessment and Learning in the Digital Age, Cape Town, South Africa, 6–7 December 2023; pp. 329–341.