Influence of Teaching Approaches on Students' Performance in Mathematics: A meta-analysis of Quasi-Experimental Studies in Africa

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Abstract

There has been poor performance in national and international mathematics assessments among African students compared to the rest of the planet. Such consistent underperformance is attributed to factors like teaching approaches. The present study reviewed and meta-analysed African research of the last 20 years on the influence of mathematics teaching approaches on students' performance with the intent to identify effective approaches that can improve performance in mathematics. The results of a random-effects meta-analysis showed that mathematics teaching approaches have an overall large significant effect ($d_{iPPC} = 1.39$) on students' performance. Specifically, the teaching approach that used concrete manipulatives showed a larger significant effect size ($d_{iPPC} = 2.736$) than any other type of teaching approach. Moreover, using meta-regression analysis, the study revealed that assessing students' mathematics performance using open-question tests had a large effect size than using multiple-choice tests. Hence, it is recommended that mathematics teachers in African educational institutions and teacher education institutions rethink mathematics teaching approaches along with the assessment format.

Keywords effect size; concrete manipulatives; mathematics teaching approach; meta-analysis; mathematics performance

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Background

African countries opted for more investment in Science, Technology, and Engineering as a winning strategy to achieve sustainable development (Mbugua et al. 2012). A recent study conducted by Belhu (2017) confirmed that a mathematics subject is a foundation for Science, Engineering, and Technological studies. Mathematics skills and competence are critical determinants for post-school and career options available to the young generation (Kurniawan et al. 2020). Nevertheless, students' performance in mathematics has been poor (Buckley et al. 2016). Student expertise in mathematics worries teachers and education stakeholders around the world because of scores from mathematics tests (Sarfo et al. 2014). To understand the grassroots factors to such a poor performance, Jameel and Ali's (2016) study pinpointed that students' poor performance in mathematics was connected to the teacher's classroom practices. The aspect of teaching approaches being the leading factors is again underlined by Fan (2012) whose study indicated that much that the best teacher's practices are determined by many factors like class size, learning environment, students' needs, teaching approaches remain a profound determinant.

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The teaching of mathematics in African schools has been cited as among the worst compared to the western and Asian countries (Muharam et al. 2019). In Africa, verbalizing the mathematical formulas and rules and presenting examples and solutions on the chalkboard have resulted in unsatisfactory performance (Jameel and Ali 2016; Kelechi 2018; Mbugua et al. 2012; Mji and Makgato 2006) and poor attitude towards mathematics for many students (Habineza 2016, 2018; Kazemi and Ghoraishi 2012; Salingay and Tan 2018; Savelsbergh et al. 2016; Uwineza et al. 2018). The study by Nsengimana et al. (2020) showed that there are undesirable teaching practices and persistence of teacher-centred in primary and secondary schools in Sub-Saharan Africa which eventually leads to poor students' performance. Mathematics teaching in many primary and secondary educational institutions in Africa has long adopted non-cooperative methods of teaching mathematics (Ayaz & Sekerci, 2015; Kazemi & Ghoraishi, 2012; HarlEn, 2013). Researchers indicate that most schools in Africa use traditional methods, especially the lecturing method, which are often viewed as unproductive, because of the crowded classes (Bofah and Hannula 2015). In Ethiopia, Hassen (2015) asserts that the most important reason for academic failure is the use of teacher-centered methods which turns some students or all of them into passive learners. In addition, traditional methods have been criticized by researchers (Carter 2016; Ganyaupfu 2013; Muema, Mulwa, and Mailu 2018) for not catering to all students especially learners with difficulties in understanding mathematics concepts. Contrary, the traditional approaches were suggested by Kazemi and Ghoraishi (2012) where teachers are interested in covering the content and completing the syllabus on time.

Akaazua et al. (2017); Carbonneau et al. (2013) and Uttal et al., (1997) suggested that mathematical ideas are abstract mental constructs, therefore, they should be represented in a more concrete way using external representations. At the beginning of the 21st century, there was a need in Africa to transform the traditional mathematics teaching approaches into new teaching approaches, often based on the constructivist concept, to promote students' cognitive understanding (Kurniawan et al. 2020). In response to the call, various countries (eg Rwanda, Kenya, Ghana, Tanzania, South Africa, Zambia, Zimbabwe, and Ethiopia) have moved from a knowledge-based curriculum to a competence-based curriculum by embracing and applying new technologies, especially in science and mathematics. Since the reform to shift from teacher-led to more student-led methods, inquiry-based learning (IBL), use of concrete manipulatives, and 5Es instructional model have been on the rise. Even though Ward (2018) noted that different schools in Africa have adopted those teaching approaches in implementing competence-based curriculum, little is known about which teaching approach most impacts students' performance in African countries. Hence, the present study.

Over the past decade, researchers and academics have improved their knowledge of effective teaching methods in the field of mathematics. Here, the use of an appropriate teaching approach exerts a powerful influence on the performance and learning of mathematics (Scherer, Siddiq, and Viveros 2020). Despite various research studies conducted in recent years (Hillmayr et al. 2020), the impact of mathematics teaching has not yet been fully discovered because many studies differ from their results. Nevertheless, researchers (Carbonneau et al. 2013; Hiebert and Grouws 2007; Yawman and Appiah-Kubi 2018) have demonstrated that the use of interactive teaching approaches could be effective for teaching a variety of mathematics concepts. Therefore, based on a review of previous studies, the current meta-analysis was conducted to evaluate which teaching methods contribute most to high school students' success in mathematics Africa.

Contribution to the literature

- Different schools in Africa have adopted different teaching approaches in implementing competence-based curriculum, the present study gives a view on how those approaches influence learners' performance.
- The study showed that teaching mathematics using concrete manipulatives may influence learners' performance more than other teaching approaches.
- This meta-analysis recommended that mathematics teachers in African educational institutions and teacher education institutions rethink mathematics teaching approaches.

Review of related literature

Overview of students' performance in mathematics

International assessment standards have shown that students in Africa continue to do poorly in mathematics (Bofah and Hannula 2015). For example, at TIMSS 2015 (See Table 1), the performance of students from Africa was among the lowest, placing African countries at the bottom while East Asian countries were the highest in all outcomes.

There was a mathematics performance decline not only in international assessments but also in regional and national assessments. For example, when looking at the results of a

Table 1 The overall mean mathematics achievement scores

Country	Overall Mean Score	Country Rank	Country	Overall Mean Score	Country Rank
Singapore	621	1	Malta	494	20
Korea	606	2	New Zealand	493	21
Chinese Taipei	599	3	Malaysia	465	22
Hong Kong SAR	594	4	Emirates	465	23
Japan	586	5	Turkey	458	24
Russian Federation	538	6	Bahrain	454	25
Kazakhstan	528	7	Georgia	453	26
Canada	527	8	Lebanon	442	27
Ireland	523	9	Qatar	437	28
England	518	10	Iran	436	29
United States	518	11	Thailand	431	30
Slovenia	516	12	Chile	427	31
Hungary	514	13	Oman	403	32
Norway	512	14	***Int. Mean Score***	***400***	**--**
Lithuania	511	15	Kuwait	392	33
Israel	511	16	Egypt*	392	34
Australia	505	17	Botswana*	391	35
Sweden	501	18	Jordan	386	36
Italy	494	19	Morocco*	384	37
			South Africa*	372	38

*African countries which participated in TIMSS 2015.

Source: IEA's Trends in International Mathematics and Science Study – TIMSS 2015 Results.

standardized test in South and East Africa, South Africa and Botswana share lower performance in mathematics compared to other STEM subjects (Maniraho 2017). In the West Africa standardized test, mathematics has become the least performed subject for many years (Zalmon and Wonu 2017). Based on Malawian students' performance in national examinations, the pass rates in mathematics have been lower than in many other subjects (Balmaceda et al. 2018). In Kenya, 18% of students who enrolled for the 2018 Kenya Certificate of Secondary Education (KCSE) examinations obtained more than grade C in Mathematics and 82% obtained below grade D and this was almost the same as in previous years (Jolif 2018). In Uganda, Kiwanuka et al. (2015) reported that although mathematics is one of the core subjects taught from nursery to secondary level, students often do poorly in the subject in national examinations.

Although Rwanda did not participate in any regional or international examinations to have a comparative picture in terms of students' performance in mathematics (Maniraho 2017); the results of national examinations published by the Rwanda Education Board in 2019 show that 52.6% of high school students fail mathematics. This failure of mathematics in international (see Table 1), regional and national examinations raised many questions about the state of teaching and learning of the subject in high schools in Africa.

Impact of mathematics teaching approaches on student performance

Although student performance depends on different factors, teaching methods have an essential role in the success of mathematics lessons (Omotayo and Adeleke 2017). According to Ganyaupfu (2013), student academic failure is strongly associated with the use of ineffective teaching methods to convey information to students. Mbugua et al. (2012) highlighted mathematics teaching methods as a major contributor to student performance in Kenya. Yeo et al. (2019) added that teacher classroom practices have a strong influence on student performance and interest in mathematics. A study by Ndihokubwayo et al. (2020) associated a low conceptual understanding with poor teaching approaches used by teachers in Rwandan schools. Zalmon and Wonu (2017) linked the failure of students in Nigeria to poor teaching habits in a mathematics classroom for many years. Similarly, the study of Muharam et al. (2019) showed that teachers' teaching approaches significantly affect students' performance.

When you search for factors that lead to poor performance in Africa, many studies overemphasize student motivation and poor mathematical attitudes due to poor teaching strategies (Kelechi, 2018; Yawman & Appiah-Kubi, 2018; Mji & Makgato, 2006). Numerous studies have shown that some teaching methods affect the performance of mathematics through the motivation of students and their attitude (Salingay & Tan, 2018; Jolif, 2018; Fan, 2012). Carter (2016) believes that students are encouraged to learn when there is an opportunity to interact with the material, especially those who have difficulties in understanding mathematical concepts easily. Learning mathematics should start with doing things that learners are familiar with, not with unfamiliar meanings and mathematics concepts. It was suggested by Oche (2012) that students should be exposed to real and effective activities to improve their attitude towards the subject. Therefore, to improve mathematics performance, teachers should use new teaching methods that are practically oriented classrooms. However, it is unfortunate that the learning of mathematics in Africa lacks hands-on activities (Fan 2012) which are expected to improve the comprehension of the concepts being studied and thus improve student academic achievement.

Numerous studies (Akaazua et al. 2017; Ayaz and Sekerci 2015; Ezeamagu, Madu, BC 2; Idris, and Njoku 2019; George and Zalmon 2019; Oche 2012; Salingay and Tan 2018; Swan and Marshall 2010; Tay and Wonkyi 2018; Yeo et al. 2019) on the effects of teaching methods on students' perceptions of comprehension and practice show interactive teaching methods that work better than others in teaching mathematics. Those methods of teaching that are witnessed to be essential in developing cognitive development studies (Akaazua et al. 2017; Ayaz and Sekerci 2015; George and Zalmon 2019; Ranjan and Padmanabhan 2018; Salingay and Tan 2018; Swan and Marshall 2010; Tay and Wonkyi 2018) are discussed in the following sections. These are (i) Concrete-Pictorial and Abstract teaching methods, (iii) 5Es model, (iv) Inquiry-Based Learning (IBL), and (v) Problem-Based Learning (PBL).

Concrete-Pictorial-Abstract (CPA) Teaching Approach and Use of Concrete Manipulatives

Concrete manipulatives are real objects or models which attract multiple senses and can be touched and transmitted by learners (Swan and Marshall 2010). They represent clear and reliable mathematical ideas that are not yet understood and can be used by students for their own practical experiences. Therefore, they are very useful and effective in building the external representation and greater mathematical concepts taught (Swan and Marshall 2010). Manipulatives allow concrete, hands-on exploration, and students are very active in mathematics where they are being used as a learning tool. This method of teaching using concrete objects is used in very few high schools in Africa (Akaazua et al., 2017; Yeo et al., 2019). However, where this teaching approach is being applied, findings of various studies (Akaazua et al. 2017; Boggan, Harper, and Whitmire 2010; Carbonneau et al. 2013; Kurniawan et al. 2020; Salingay and Tan 2018; Sarfo et al. 2014; Uttal et al. 1997) showed its positive impact on students' achievement and understanding of complex mathematical concepts. In Nigeria, the study by Akaazua et al. (2017) showed that manipulatives positively affect students' mathematics learning and performance more than any traditional teaching approach.

Teaching using Concrete-Pictorial-Abstract also known as the CPA approach ranges from concrete objects to pictorial representations, to invisible symbols and problems. In the first phase, all the abstract concepts are presented using complementary concrete materials and students use them to create a problem model instead of teacher solving it. During the pictorial stage, concrete material presentations are used to allow students to make mental connections between the newly used concrete object and the invisible images, drawings, or models representing the problem objects. In the final stage, mathematics symbols and notations are used to solve the problem.

The use of real objects through pictures to symbols helps students with difficulties in learning mathematics (Salingay and Tan 2018). It is for this reason that Hiebert and Grouws (2007) suggested the use of concrete materials to overcome any difficulties students may have in learning mathematics. In addition, Yeo et al. (2019) and Sarfo et al. (2014) suggested the use of the CPA approach in helping students to understand Algebra and to improve students' cognitive understanding of fractions. Salingay and Tan (2018) used CPA incorporated with a teacher-led explanatory approach (TLE) to improve student performance and was more effective than TLE. Unfortunately, very few countries in Africa (Jolif, 2018; Kurniawan et al., 2020) have adopted and implemented the CPA approach in their curriculum.

5Es instructional model

The 5E Instructional Model (also known as one of the constructivist-based teaching methods) contains five consecutive sections namely: Engage/Excite, Explore, Explain, Elaborate, and Evaluate (see Figure 1).

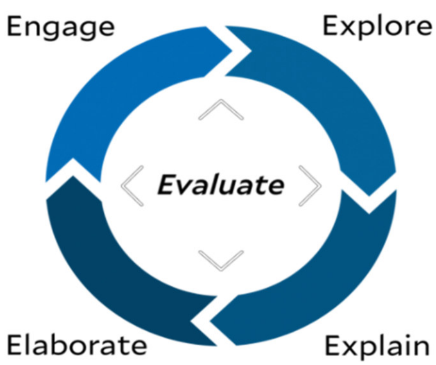

Figure 1 The 5Es teaching model
(Source: Engleman and Bybee 2001)

This model is mainly used to stimulate learners' observations, questioning, and thinking. In the first phase, students participate by developing specific by creating cognitive conflict to attract their interest in the study. At this step, a teacher uses discrepant events to raise students' questions. The generated interest helps students to use specific concrete experiences to make predictions. Later, hands-on experience is given to learners, and they work collaboratively to explore the new concepts through observations, questioning, investigating and testing their predictions. Learners are given time to share an understanding of the ideas explored and to ask questions to clarify further misunderstood ideas. In addition, the teacher introduces key definitions, formulas, and other scientific information. Towards the end of the lesson, the teacher provides a daily life problem that requires applying skills and knowledge acquired to assess if the learners have scientifically understood the concept.

According to Ayaz and Sekerci (2015), the 5Es teaching model is one of the most recommended teaching methods within a constructive learning approach and is more effective in promoting mathematical success compared to traditional methods (Ranjan and Padmanabhan 2018). Although this approach is effective in promoting and improving student performance, it takes time to prepare classroom classes based on 5Es (Enugu 2016).

Inquiry-Based Learning and Problem-Based Learning (IBL/PBL) Methods

Problem-based learning (PBL) and Research/Inquiry-based learning (IBL) are defined as teaching approaches where learning starts with a situation of daily life problems by which learners use the skills, knowledge, and experience they acquired to solve the problem. Learners interpret the problem, gather the necessary information to make scientific conclusions. The two approaches actively promote STEM teaching because of their ability to lead to the competence and skills needed by technologically advanced societies (HarlEn 2013). Kazemi and Ghoraishi (2012) showed that the Problem Based Learning (PBL) approach affects students' performance in mathematics rather than traditional methods.

Teacher-led explanations

The teacher-led explanations method also known as the teacher-focused or traditional method relies heavily on textbooks in which the teacher instructs students to learn memorization and thus does not develop their problem-solving skills and decision-making skills. Carter (2016) noted that students who taught using a project-based learning approach had a higher level of motivation and performance than those who were taught using teacher-led explanations.

Purpose of the study

The gist of this paper is to look at how mathematics teaching approaches affect students' academic performance. The paper addresses the following questions:

1. To what extent do mathematics teaching approaches affect students' performance?
2. How does the size of the result vary in all studies?
3. Are the results of student performance in mathematics affected by the timing of the intervention, the assessment features, and the type of teaching method used?

Methodology

We used the meta-analysis method to incorporate the results of quasi-experimental research with the effect of teaching approaches on academic success in high school mathematics. In the first step, the literature on the effect of teaching methods on students' mathematics performance was extensively searched in various databases such as *Google Scholar, ResearchGate, Web of Science, ERIC, and Scopus* by pre-screening published papers based on reading study material. Those repositories are considered because the journals or conference papers referenced in them are considered of good quality (Oche 2012). In cases where important aspects of the study were not identified and did not appear, the complete text was touched on.

Researchers also searched for articles on search collections and their compilation; *mathematics teaching approaches, mathematics performance, effect of teaching approach on academic performance, best mathematics teaching approach, STEM innovative teaching approaches, teachers' practices in teaching mathematics, what constitutes effective mathematics teaching?* For further consideration, the following inclusion criteria were assessed:

- The study should have been carried out in Africa between 2000-2020.
- The study must be a master's or doctoral thesis, or an article published in scientific journals written in English.
- The study examined the effect of the mathematics teaching approaches on students' performance.
- There will be no inclusion of the same study more than once even if it is presented at a conference and published in a journal also.
- The study should contain all information needed to estimate effect size (ES).

Later, complete paper was checked to make sure that each statistical data required for inclusion within the meta-analysis were reported within the paper. Therefore, only 12 published papers that reported enough statistical information were retained for review. In the third step, the full papers were studied to look at the features of the test, the statistical analysis used, the study area, the type of intervention, and the duration.

Coding of studies

The selected studies were coded based on the general characteristics of the studies to later explain the heterogeneity exhibited by the effect sizes. Many of the coding features, such as research authors, country, sample sizes, assessment features (format of the test and origin of the test), type of teaching approach used, and intervention duration were extracted to support the study validity.

Statistical analysis and interpretation

A good meta-analysis involves looking for a relationship between outcome size and study characteristics found in them (Nakagawa and Cuthill 2007). Effect size is a statistical measure of the dissimilarity between two groups by quantifying and interpreting the effectiveness of a specific treatment, related to other comparisons and it has multiple benefits over the use of statistical value tests alone (Nakagawa and Cuthill 2007). According to Schwichow et al. (2016), it is common in educational studies to measure the effectiveness of interventions in relation to the mean change in outcome variable so that change in the control group can be compared to change without treatment. Therefore, experimental and control groups cannot be considered to be equally at first, which is why Morris and DeShon (2002) have suggested that the magnitude of the pretest-posttest-control (PPC) effect provides a better indication of the treatment effect.

In the present study, the outcome size in each study is estimated as the change in the mean difference for the experimental and control situation in which estimates of the mean and standard deviation in both groups in the pretest and posttest subjects were extracted from each PC study. The sample size of the impact size was calculated using the formula proposed by Morris (2008), [i.e., equation 1].

$$d_{PPC}=cp\left(\frac{(M_{post-exp.g}-M_{pre-exp.g})-(M_{post-Cont.g}-M_{pre-Cont.g})}{SD_{Pre}}\right). \quad (1)$$

In the above formula (Equation 1) $M_{post-exp.g}$ stands for the mean scores at posttest for the treatment group, $M_{pre-exp.g}$ stands for the mean scores at pretest for the treatment group, $M_{post-Cont.g}$ stands for the mean scores at posttest for the control group, $M_{pre-Cont.g}$ stands for the mean at pretest for the control group, SD_{pre} is the pooled pretest standard deviation for the intervention and control groups, and Cp is the correction factor for small sample sizes (Morris 2008) described as in [i.e., equations 2 and 3].

$$Cp=1-\frac{3}{4(n_e+n_C-2)-1}, \quad (2)$$

The pooled standard deviation is defined as

$$SD_{Pre}=\sqrt{\frac{(n_e-1)SD^2_{Exp.1}+(n_c-1)SD^2_{Cont.1}}{n_e+n_c-2}}. \quad (3)$$

In our study, the experimental group would be the one who was given the 'new' method of teaching mathematics and the 'control' group would be the one who was given the 'normal' mathematics teaching method. Therefore, the effect size, d_{PPC}, would be defined as the variation between the mean scores of groups exposed to the "new" approach and the groups exposed to the "normal" approach over the combined standard deviation of both groups. Values of d_{PPC} are interpreted based on the conditions suggested by Cohen (1988): $[0.2, 0.5[$ indicates a small effect; $[0.5, 0.8[$ indicates a medium effect, and ≥ 0.8 indicates a large effect. According to Becker (1988), the standardized mean change value, d_{PPC}, shows how much large (or small) change in the intervention group was compared to change in the control group. Therefore, a positive value d_{PPC} would indicate that the intervention group performs well compared to the control group. In contrast, a negative number will indicate that the control group is doing well compared to the intervention group.

As various studies were combined to perform meta-analyses, we would expect that there would be variability in intervention outcomes (Morris and DeShon 2002). The actual effect of different interventions will be different from study to study as the published studies were conducted by different people in different countries at different times (Savelsbergh et al. 2016), therefore, the random effect models are used. Furthermore, mixed-effect models were used to examine the role of moderators in the intervention effect. To test whether the effect estimates are heterogeneous, the Q-statistic was applied. The variability that might occur due to heterogeneity between studies was quantified by considering I^2 index (Morris 2008). According to Benavides-Varela et al. (2020), high value I^2 means that variation between results are linked to actual dissimilarities across studies while a small value of I^2 means that outcomes across studies are related and possible difference might be due to arbitrary selection error. To ascertain the degree of publication bias present in the study, trim-and-fill analyses was done and the funnel plot of effect sizes was assessed to detect possible irregularity that may occur (Scherer et al. 2020). The statistical analysis was done under the Metafor package of R software (R Core Team, 2019).

Results

In this section, we first reported the descriptive statistics of the 12 included studies. We also described the overall meta-analysis for the effect of mathematics instructional methods on students' performance and later we looked at the effects of types of teaching approaches, intervention duration, and assessment features (assessment test format and origin).

Descriptive statistics of included studies

It was noticed that number of studies decreased steadily when African studies were only considered for inclusion (only 24 out of 502 were considered). This indicates the gap in studies related to the effects of mathematics teaching approaches on learners' performance in Africa. Based on our inclusion criteria, 12 studies published from 2000 to 2020 were included in this study for review and meta-analysis, most of them after 2015. Figure 2 below shows step-by-step the detailed screening process of how studies were included or excluded from the study and Table 2 shows a summary of the descriptive information on each study included.

Three-quarters of the studies (9 out of 12) were conducted in Nigeria, two in Ghana and one in Kenya. Therefore, studies are not evenly spread out by region as there are certain countries in which the research has never been conducted (Rwanda, Burundi, Burkina Faso, Uganda, Madagascar, and many others). The sample size of selected studies varied between 49 and 389 with most of the studies having above 100 participants. On average the intervention lasted between 3 to 6 weeks.

Overall effects of mathematics teaching approaches on students' academic performance

For 12 independent studies, the effects of mathematics teaching approaches on overall performance were evaluated and explored in this paper. The forest structure (see Fig. 3) below shows the estimated effect size of each study as well as the general effect size estimates and 95% CI over 12 studies.

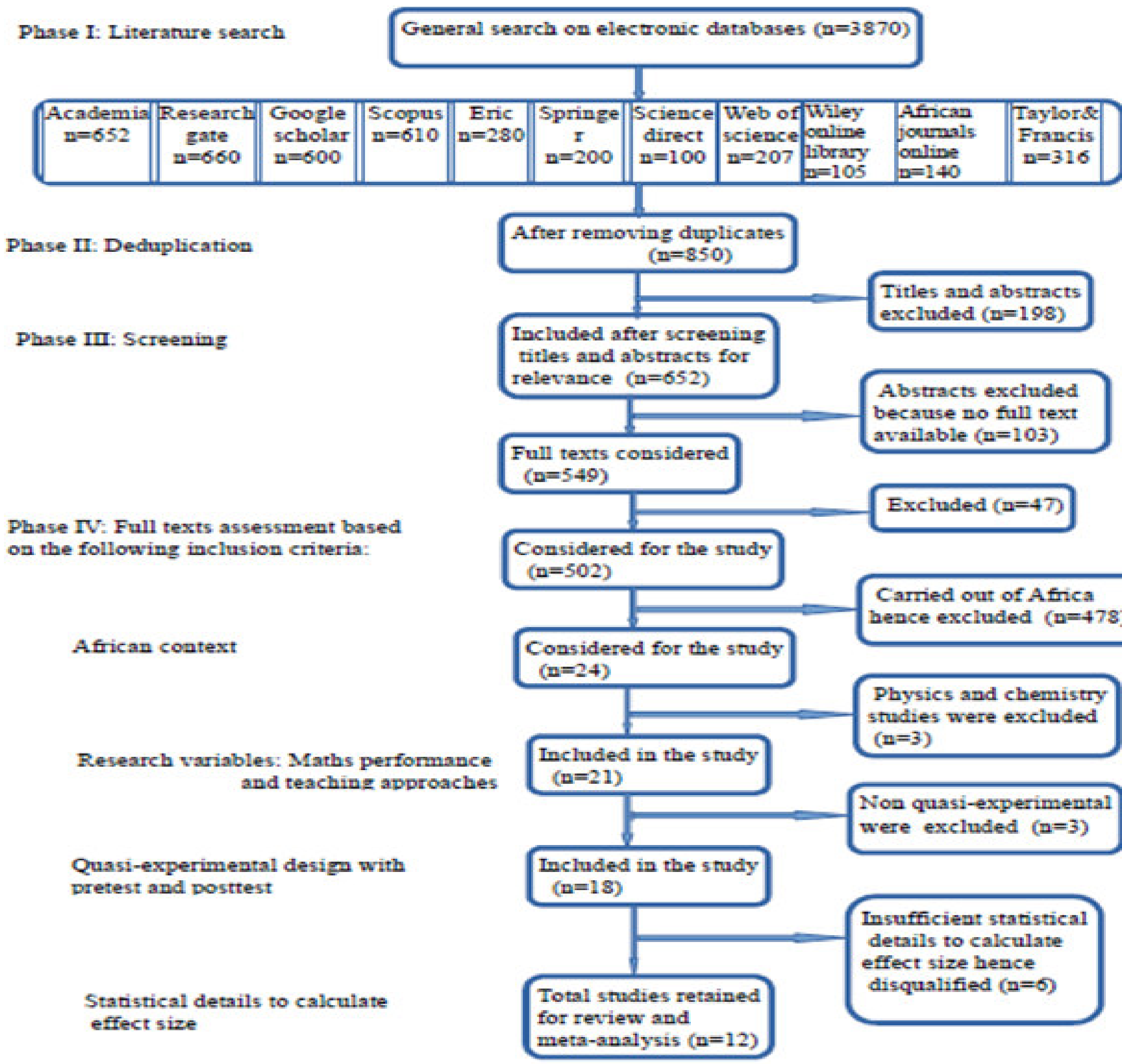

Figure 2 The detailed study screening process

A random-effect meta-analysis showed a strong positive and significant treatment effect, with $d_{iPPC} = 1.39$, 95% CI (0.580; 2.200), p = 0.0008, suggesting that students in the experimental groups showed a very good mathematics performance compared to their counterparts in the control groups. This implies that teaching approaches affected students' performance.

However, studies by George and Zalmon (2019), Akaazua et al. (2017) reported very large effect sizes $d_{iPPC} = 3.54$ $d_{iPPC} = 3.9$ respectively than others (see forest structure). Innovative teaching approach and teaching using concrete-manipulatives have shown significant and large effect sizes ($d_{iPPC} = 3.54(3.26; 3.82)$ and $d_{iPPC} = 3.90(3.46; 4.34)$respectively) compared to studies that used videotaped and ICT-integrated teaching approaches ($d_{iPPC} = 0.38(0.18; 0.58)andd_{iPPC} = 0.21(-0.07; 0.49)$ respectively).

Table 2 Descriptive information for each included study

								Pre-test		Post-test	
Author(s)	Location	EL	IT	ID	AF (TT-TO)	SAM	N	M	SD	M	SD
Oche (2012)	Nigeria	SC	CLM-ABM	4w	MCT-RM	ANOVA	50 - 50	15.56-23.36	5.45-4.76	10.07-25.21	5.02-3.98
Ezeamagu,Madu,Idris,& Njoku (2019)	Nigeria	PR	CLM- 5Es	4w	OQT-RM	ANOVA	62 - 72	15.16-31.43	6.06-9.38	9.06-29.32	4.64-9.07
George & Zalmon (2019).	Nigeria	SC	CIS- IIS	6w	MCT-RM	ANCOVA	194 - 204	21.24-21.71	5.40-6.35	42.23-63.65	8.94-14.6
Tay & Wonkyi (2018)	Ghana	SC	CLM-GeoGebra	5w	OQT-RM	ANCOVA	24- 25	9.67-9.40	9.67-6.42	19.79-28.36	5.29-6.30
Sadiq (2019)	Nigeria	SC	CLM- CIA	6w	OQT-RM	ANOVA	193- 184	6.44-17.18	4.05-3.33	8.64-26.71	5.45-2.42
Nkechi (2017)	Nigeria	SC	CLM-MMS	4w	MCT-RM	ANCOVA	86-84	17.43-21.60	4.89-5.34	20.32-28.03	4.65-4.96
Aroh (2006)	Nigeria	SC	CLM-VTI	3w	MCT-RM	ANCOVA	86-87	2.72-3.26	1.43-1.9 1	4.43-5.61	1.77-2.15
Mensah-Wonkyi & Adu (2016)	Ghana	SC	CLM-IBT	5w	OQT-RM	T-test	38-41	12.61-10.71	9.16-2.14	18.65-33.00	5.44- 6.32
Muema, Mulwa & Mailu (2018)	Kenya		CLM-ICT Integrated	3 w	MCT-RM	CA	60- 60	35.05-35.50	12.6-12.78	37.80-40.88	12.7-12.59
Akaazua et al. (2017)	Nigeria	SC	CLM-CMA	6w	OQT-RM	T-test	108-103	24.14-25.37	2.08-1.45	28.42-36.69	3.95-3.22
Omoruan & Osadebe(2020)	Nigeria	Pr	CIA-CLM	4w	MCT-RM	ANCOVA	34-34	25.02-12.47	2.54-1.56	28.34-10.89	1.58-6.78
Ogbonna (2016)	Nigeria	SC	CIA-CLM	4w	OQT-RM	ANCOVA	66-64	0.97-0.77	2.76-1.21	5.29-2.11	5.59-1.30

EL= Educational level: SC = secondary; Pr=primary; AF(TF-TO)=Assessment features (Test format-Test origin) ; SAM=Statistical Analysis method; N = total participants in control – experimental group; M = Mean in control – experimental group; SD = Standard deviation in control – experimental group; MCQ-RM= Multiple choice test-Researcher made; OQT-RM= Open question test-Researcher made; ID=Intervention duration (w=weeks); IT=Intervention type; CLM=conventional lecturing method; ABM=activity-based method; 5Es=5Es instructional model; IIS=innovative instructional strategies; CIS=conventional instructional strategies; CIA=Constructivist instructional approach; MMS=Mathematical modeling strategy; VTI=video-tape instruction, IBT=Inquiry-based teaching, CMA=concrete manipulatives approach; ANCOVA=Analysis of covariance; CA=correlation analysis.

Overall effects

For 12 independent studies, the effects of mathematics teaching approaches on overall performance were evaluated and explored (see Table 3). The forest structure (see Figure 2) shows the estimated effect size of each study as well as the general effect size estimates and 95% CI over 12 studies.

the experimental groups showed a very good mathematics performance compared to their counterparts in the control groups. This implies that teaching approaches affected students' performance.

However, studies by George and Zalmon (2019), Akaazua et al. (2017) reported very large effect sizes $d_{i\mathrm{PPC}} = 3.54$ $d_{i\mathrm{PPC}} = 3.9$ respectively than others (see forest structure).

Table 3. Meta-analysis data of mathematics teaching approaches and students' academic performance.

Study			Characteristics				$d_{i\mathrm{PPC}}$	
Author	Year	SS	Location	Intervention	Control group	ID	ES	Variance
Oche	2012	100	Nigeria	Activity-Based Method	Lecturing	4w	1.42	0.03
Ezeamagu Madu, Idris, & Njoku	2019	134	Nigeria	5Es	Lecturing	4w	0.49	0.02
George & Zalmon	2019	398	Nigeria	Innovative	conventional	6 w	3.54	0.02
Tay & Wonkyi	2018	49	Ghana	Geogebra	Lecturing	5 w	1.06	0.06
Sadiq	2019	377	Nigeria	Constructivist	conventional	6 w	-1.03	0.01
Nkechi	2017	170	Nigeria	Mathematical modelling	Teacher-led explanations	4 w	0.69	0.02
Aroh	2009	173	Nigeria	Video-Taped	Lecturing	3 w	0.38	0.01
Mensah-Wonkyi & Adu	2016	79	Ghana	Inquiry-based	Lecturing	5 w	2.46	0.07
Muema, Mulwa & Mailu	2018	120	Kenya	ICT integrated	Lecturing	3 w	0.21	0.02
Akaazua et al.	2017	211	Nigeria	Concrete-manipulatives	Lecturing	6 w	3.90	1.06
Omoruan & Osadebe	2020	68	Nigeria	Constructivist	Lecturing	4 w	2.30	0.07
Ogbonna	2016	130	Nigeria	Constructivist	Lecturing	4 w	1.38	0.03

SS = Sample size; ES=Effect size; ID=Intervention duration (w=weeks)

A random-effect meta-analysis showed a strong positive and significant treatment effect, with $d_{i\mathrm{PPC}} = 1.39$, 95% CI (0.580; 2.200), p = 0.0008, suggesting that students in

Innovative teaching approach and teaching using concrete-manipulatives have shown significant and large effect sizes ($d_{i\mathrm{PPC}} = 3.54(3.26; 3.82)$ and

Table 4 Results of leave-one-out analysis

Study	Year	d_{iPPC}	Stand. Error	95% CI	P-value	I^2
Oche	2012	1.39	0.454	[0.50;2.28]	0.0022	98.98
Ezeamagu,Madu,Idris,&Njoku	2019	1.48	0.445	[0.60; 2.35]	0.0009	98.90
George & Zalmon	2019	1.19	0.399	[0.41; 1.98]	0.0028	98.63
Tay& Wonkyi	2018	1.42	0.452	[0.54; 2.31]	0.0017	99.01
Sadiq	2019	1.61	0.384	[0.86; 2.37]	0.0000	98.36
Nkechi	2017	1.46	0.449	[0.58; 2.34]	0.0012	98.91
Aroh	2009	1.49	0.443	[0.62; 2.35]	0.0008	98.77
Mensah-Wonkyi & Adu	2016	1.30	0.441	[0.43; 2.16]	0.0033	98.97
Muema, Mulwa & Mailu	2018	1.50	0.439	[0.64; 2.36]	0.0006	98.86
Akaazua et al.	2017	1.16	0.380	[0.42; 1.91]	0.0022	98.59
Omoruan & Osadebe	2020	1.31	0.444	[0.44; 2.18]	0.0032	98.98
Ogbonna	2016	1.39	0.454	[0.50; 2.28]	0.0021	98.98
	Mean	1.392	0.432			98.827

$d_{iPPC} = 3.90(3.46; 4.34)$respectively) compared to studies that used videotaped and ICT-integrated teaching approaches ($d_{iPPC} = 0.38(0.18; 0.58)$ and $d_{iPPC} = 0.21(\ \ 0.07; 0.49)$ respectively).

To understand the magnitude of the variant effect sizes in all studies, a Q-test of the effect size variability was performed under random effects meta- analysis. As noted by Hedges and Olkin (2014), the Q-test has little potential to find true differences between the magnitude of meta-analysis results involving very few studies (k <30), therefore, as suggested by Higgins and Thompson (2002) the I^2 index is also considered to evaluate the magnitude of the heterogeneity indicated by the effect sizes. The heterogeneity was Q(df = 11) = 1039.2703, p-value < 0.0001, with high index values (I^2 = 98.86%), suggesting that significant differences among effect sizes may be related to actual differences among the characteristics of the studies.

A leave-one-out method was used to check whether a single outlying study could be the source of heterogeneity, therefore, we iteratively removed studies and rerun the meta-analysis. The leave-one-out analysis results (see Table 4) shows how individual study affects the overall effect size estimates of the studies included in the analysis. According to Coe (2002), significant changes when a study is removed are interpreted as uniform deficits and unreliable results. Using the leave-one-out method, all studies showed very large effect levels that varied between 1.16 and 1.61, and diversity was consistently high with I^2 ranging from 98.36% to 99.01%. When there is significant heterogeneity, study characteristics that might account for the dispersion in the summary of effect should be carefully considered (Hedges and Olkin 2014). Study characteristics: type of teaching approach, intervention duration, and assessment features were selected and analyzed to moderate the intervention effect.

The funnel plot in Figure 4 shows that studies are distributed symmetrically around the average effect size hence there is no visual indication of publication bias.

To further assess whether the effect sizes of student academic performance in mathematics depend on the type of teaching approach used in the classroom, we conducted a meta-regression analysis with each teaching approach as predictor variables. The results of the meta-regression analysis are presented in Table 5.

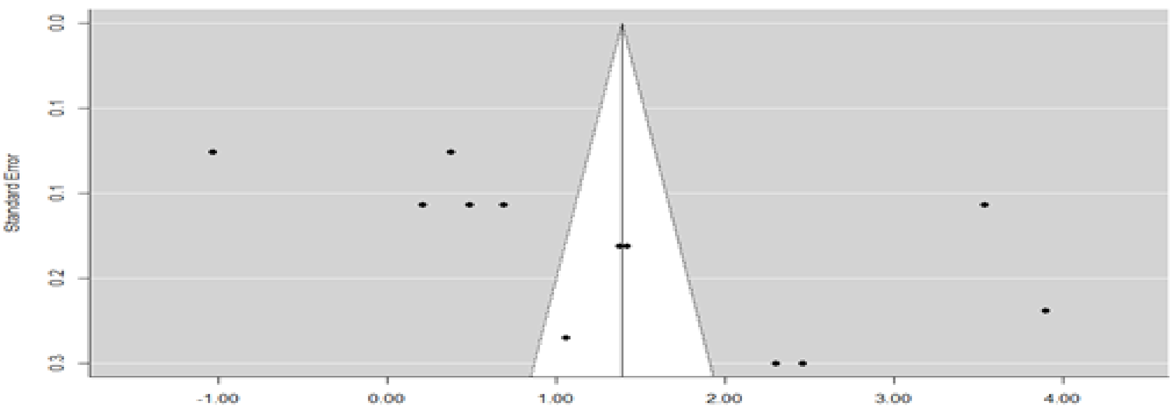

Figure 4 Funnel plot

Does mathematics performance depend on type of the teaching approach, intervention duration, and assessment features?

To understand why some studies report larger effect levels than others (Benavides-Varela et al. 2020), we conducted a meta-regression analysis to decide which study characteristics influenced the effects. In this section, researchers evaluated the role of the type of teaching approaches used in mathematics class, intervention duration, and assessment features as moderators. Using meta-regression models, the effect of (1) type of teaching approach, (2) intervention duration, and (3) assessment features on students' performance were examined separately. For the assessment features, we considered the origin of the assessment test (researcher-made/preexisting test) and its format (open question test/multiple-choice questions).

For the ten teaching approaches, only three (concrete manipulatives, mathematical modelling, and innovative teaching approach) significantly moderated students' mathematics performance. A teaching approach that used concrete manipulatives showed a very large significant effect size than any other type of teaching approach ($d_{iPPC} = 2.736$(0.142; 5.329)). Also, studies that used mathematical modelling and innovative teaching approaches generated a positive large significant effect on the students' performance (d_{iPPC} = 2.644(0.580; 5.229); d_{iPPC} = 2.346 (0.354; 5.047) respectively). Surprisingly, the intervention duration did not significantly moderate the study outcome (i.e., the test of the moderator

Table 5 Results of meta-regression models

Moderator variables	Number of studies (k)	Meta-Regression Models: Estimates	SE	95% CI	p-value	Test of Moderators: QM (p-value)
Intervention duration (ID)	12	Intercept: -1.134	1.743	[-4.548; 2.282]	0.515	2.212 (0.137)
		ID: 0.561	0.377	[-0.178; 1.301]	0.137	
Activity-based teaching approach	12	Intercept: 1.390	0.454	[0.500 ;2.280]	0.002	0.0004 (0.985)
		Activity-based: 0.029	1.571	[-3.049; 3.109]	0.985	
5Es instructional model	12	Intercept: 1.475	0.445	[0.603; 2.348]	0.001	0.410 (0.522)
		5Es: -0.985	1.537	[-3.998; 2.028]	0.522	
Innovative teaching approach	12	Intercept: 1.194	0.3993	[0.411; 1.976]	0.0028	2.899(0.008)
		Innovative: 2.346	1.3779	[0.354; 5.047]	0.0086	
ICT-based	12	Intercept: 1.674	0.4696	[0.754; 2.595]	0.0004	1446 (0.229)
		ICT-based: -1.128	0.9382	[-2.967; 0.711]	0.229	
Constructivist	12	Intercept: 1.5669	0.4891	[0.608; 2.525]	0.001	0.509(0.476)
		Constructivist: -0.6982	0.979	[-2.616; 1.220]	0.4757	
Mathematical modelling	12	Intercept: 1.614	0.384	[0.862; 2.366]	<0.0001	4.015(0.045)
		Maths-modeling: 2.644	1.319	[0.580; 5.229]	0.0451	
Inquiry-based	12	Intercept: 1.297	0.441	[0.433; 2.161]	0.003	0.570(0.450)
		Inquiry-based: 1.163	1.540	[-1.856; 4.182]	0.450	
Concrete manipulatives	2	Intercept: 1.164	0.380	[0.419; 1.909]	0.002	4.274(0.038)
		Concrete manipulatives: 2.736	1.323	[0.142; 5.329]	0.038	
Assessment features: Test format and origin	12	Intercept: 0.53	0.615	[0.160; 2.572]	0.026	0.004(0.009)
		MCT: 1.366	0.869	[0.650; 1.756]	0.005	
	12	Intercept: 0.530	0.614	[0.217; 2.622]	0.020	0.004(0.045)
		OQT:1.419	0.869	[0.756; 1.650]	0.019	
	12	RM:1.392	0.414	[0.579; 2.204]	0.001	0.024(0.005)

was not significant for intervention duration, $Q_M = 2.212\ (p_{-value} = 0.137)$).

Discussions

All studies conducted so far have suggested that the mathematics teaching approach matters in learning and performance. However, those studies did not always yield the same results. The current study aims to explore the effect of mathematics teaching approaches on learners' achievement. In addition, we assessed whether the impact of mathematics teaching approaches on students' achievement was influenced by intervention duration and assessment features. Regarding the influence of teaching approaches on students' achievement, the use of concrete manipulatives, mathematical modelling, and innovative teaching approach affected the performance of most students. Similarly, according to the findings of Carbonneau et al (2013), the use of concrete manipulatives was found to be an appropriate strategy to help students solve problems, improve their mathematics comprehension and their academic performance.

The period of teaching has been recognized as an important predictive variable for learning and performance in high schools (Carbonneau et al. 2013). In examining if the effect level of teaching methods depends on the duration of the intervention, the study found differences between studies with a longer intervention duration and studies with a shorter intervention duration. However, these differences are not statistically significant. This contradicts the Uttal et al (1997)'s findings, and maybe disappointing because academic researchers and educators expect long-term intervention to be "very effective". Alternatively, this finding seems to be promising because it shows that there are various factors that influence mathematics learning and performance in high schools.

Concerning the assessment features, the test format and test origin (i.e. test made by the researcher and pre-existing test) moderated the study outcomes. It was found that studies that assessed students' mathematics performance with real and open-response mathematics tests show larger effect sizes ($d_{i\text{PPC}} = 1.419\ (0.756;\ 1.650)$ than studies that used mathematics multiple-choice tests ($d_{i\text{PPC}} = 1.366\ (0.650;\ 1.756)$. Our results are consistent with Ross (1988) and Schwichow et al (2016)' findings with the view that open-response tests are more sensitive to treatment outcomes. To be precise, although all types of testing tasks need to understand mathematics concepts, multiple-choice test activities give students limited thinking time and search space. Multiple-questions focus on low-level instructional objectives as they give students who are not prepared for the opportunity to guess, and with the right guess, they get credit for things they do not know. Therefore, they do not provide a clear distinction of the students' thinking and, as a result, less distinguishing between scores and students' understanding.

Finally, we investigated the effect of the test origin used to assess intervention effectiveness. Though Schwichow et al. (2016) found statistically insignificant differences between self-developed (made by researcher him/her-self) and previously used-tests (made by other researchers/educators), we found that studies where researchers developed their tests have larger effect levels than studies that used existing tests. This cannot be strange because Ross (1988) also found that studies that used researcher-made tests had larger effect levels than studies that used previously existing tests. Our study likely obtained different results because (Schwichow et al. 2016)' study considered retention time between teaching and assessment which our study and Ross's study did not consider. Our findings show that, according to Chiu (1998), existing tests produce less positive results than those developed researchers. The difference supports Rosenshine (1994) findings that existing assessments are less sensitive to measuring intervention impact than self-developed tests. This is due to the fact that pre-existing tests are likely to measure students' achievement in a broader sense and do not focus on the ability to do a particular task.

Limitations

The reviews are deliberately limited to studies conducted in Africa. The rigorous inclusion condition resulted in a very small number of included subjects. Therefore, due to the small number of studies, care should be used to generalize the findings. Though the effect of assessment format and assessment origin on students' performance was found to be significant, the timing of assessment and time delay between intervention and assessment are interesting variables that can be considered in future research to find any firm conclusions about the effect of assessment features on performance. The timing of assessment and time delay between intervention and assessment were not considered in this study because they were not reported in the selected studies.

Conclusions

So many concerns have been raised on teaching approaches used in mathematics class, especially in Africa. Studies (Oche, 2012; Akaazua et al., 2017; George & Zalmon, 2019; Kazemi & Ghoraishi, 2012) showed that most African countries have long embraced non-interactive teaching approaches, therefore, mathematics poor performance has persistently occurred. From the literature review process, it was unfortunately noticed that very few studies on the effectiveness of mathematics teaching approaches on learners' achievement in Africa were conducted (only 12 studies conducted in Africa were found). The current meta-analysis study served to examine how teaching approaches influenced students' mathematics performance. This study found that mathematics teaching approaches affected significantly the students' performance in mathematics. The overall effectiveness of the teaching approach in predicting mathematics performance was ($d_{iPPC} = 1.39$) which means that teaching approaches used in mathematics class had a very large effect size. However, the teaching approach that used concrete manipulatives showed a very large significant effect size ($d_{iPPC} = 2.736$) than any other type of teaching approach. This implies that students' performance could be improved by teaching mathematics concepts using real objects that learners may view and physically manipulate to model their understanding of the abstract concepts. As it was said by the Chinese philosopher Confucius (551 BC to 479 BC) that "I hear and I forget. I see and I remember. I do and I understand", learners should be taught in a way that they visualize and manipulate concrete objects. This is supported by the learning theory of Piaget (1952) and Bruner (1966) which suggests that students can understand symbols and abstract concepts once they have experienced the ideas on a concrete level. Sutton and Krueger (2002) extended this by affirming that the use of manipulatives does not only helps directly in the cognitive process but also is exciting, engaging, and enhances both students' interest in and enjoyment of mathematics concepts.

The study surprisingly did not find any significant difference between studies with long intervention duration and the ones with short intervention duration. This implies that how long a teacher is going to teach the concepts has no impact on students' performance. Therefore, teachers should ensure that students understand the concepts rather than extending the teaching period. In other words, teachers should focus on the teaching practices that can motivate and engage learners in learning mathematics. In addition to the teaching practices, teachers have also to make sure that they are using the right ways of assessing students' achievement. The present study revealed that assessing students' mathematics performance using open-response tests had large effect sizes than using multiple-choice tests. This finding indicates that learners' cognitive abilities should be assessed by letting asking them to demonstrate their understanding of the concepts learnt.

Although this meta-analysis found the effect of test format and test origin on students' performance, the timing of test is an interesting variable that should be considered in future research to make any strong conclusions about the impact of test features on performance. Researchers believe that intervention characteristics examined in this meta-analysis study are common in educational context and therefore, the findings also apply to other educational level (primary and tertiary education). Researchers recommended that mathematics teachers in African educational institutions and teacher education institutions rethink mathematics teaching approaches to improve the future educational interventions to achieve quality mathematics teaching practices as well as students' performance.

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Authors' contributions

Emmanuel Iyamuremye conceptualized, drafted the manuscript and analyzed the data. Irenee Ndayambaje and Charles Magoba Muwonge provided overall supervision of the study. All authors read and approved the final version of the manuscript.