Redesigning a mixed-method research study during a pandemic: A case study from Nigeria and Australia

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One major challenge researchers have faced during the disruptions resulting from the Covid-19 pandemic is how to adapt to the global virus and, at the same time, make good progress in their research pursuits. Also, many international researchers have suspended ongoing research in developing countries due to inadequate online facilities in these countries. This article identifies innovative methodologies that can be employed to carry out mixed-method research in a non-technologically advanced country and reflects on the benefits and limitations of carrying out such rigorous research during difficult times. The mixed-method research design reported here combines tests and open-ended reasons for procedures to explore the impacts of two pedagogical practices on students' mathematical understanding. In particular, the methodological framework leverages the aims of the research, the theoretical background, standard ethical practice, and Covid-19 safety precautions. This article contributes to the methodological approaches for carrying out mixed-method research during unprecedented times.

Introduction

The role of methodology in research investigations is as important as finding solutions to the research problems. In the same way, the credibility of research findings largely depends on the validity of the methodology employed to gather information on a phenomenon (Wellington et al., 2005). A research methodology states the what, how, and why of the research, which means the research methodology not only explains the procedures for an investigation, but also justifies the approaches that have been utilised to provide solutions to the research questions. The methodology reflects on the objectives, the procedures, and the varying circumstances of the research subjects. The Covid-19 pandemic is an event that has disrupted many research activities, including planning and collecting data, especially where human subjects are involved. While many researchers are struggling to continue with the methods already in place for their planned research, others are reconceptualising their methodology to accommodate Covid-19 safety precautions. This article outlines an innovative methodology undertaken during the pandemic to explore the impacts of two pedagogical practices on students' mathematical understanding. Given the context of the study is Nigeria, which is a developing country with little or no facilities for students' online learning during the pandemic, a critical reflection on the benefits and limitations of the methodological conceptualisation was undertaken. To authenticate the research findings and conclusions and to acknowledge the complex social relations, power, and ethics of human beings, this research adapted the mixed-method research design. Although the methodology was re-conceptualised due to Covid-19, all the methods and approaches selected for this research were reasonably justified and validated, and followed standard ethical guidelines for social science research.

Context of the study

Nigeria, officially known as the Federal Republic of Nigeria, is a country in West Africa with an approximate area of 923,768 square kilometres and over 200 million people. Nigeria is a heterogeneous society that operates a 9-3-4 system of education (Nigerian Educational Research and Development Council, 2004). Students attend nine years of basic education (six years of primary education and three years of junior secondary education), followed by three years of senior secondary education, and finally, four to six years (depending on the course of study) of tertiary education. Students who have attended the nine years of basic school and passed the universal, performance-based examinations organised by the state government are qualified to attend senior secondary schools. Students who continue their education to senior secondary level choose one discipline from humanities, science and mathematics, business studies, or technology. Moreover, students must complete four compulsory subjects: English, mathematics, civic education, and an entrepreneurial subject. The primary goal of Nigeria's secondary school education is to increase the employability of high school graduates through a stronger focus on vocational training and preparing some students for tertiary education (Nigerian Educational Research and Development Council, 2014).

Despite mathematics being a compulsory subject, Nigerian secondary school students have not been able to demonstrate an adequate understanding of mathematical ideas (Awofala, 2017; Kolawole & Ojo, 2019; Omobude, 2014; Ugboduma, 2012). For example, students are not able to display the required mathematical skills and knowledge needed for vocational training, onward learning, and employability. This deficit is influenced by the nature of teachers' instructional practices and the learning style most students adopt to pass examinations (Adunola, 2011; Awofala, 2017). Evidence from research has indicated that students often learn by memorisation rather than understanding the relevance and applicability of several educational domains (Khalid, 2006; Magen-Nagar, 2016; Omobude, 2014). As a country seeking all-round development, the role of mathematical knowledge in improving the social and economic wellbeing of citizens cannot be over-emphasised, due to its relevance in every field of human endeavour (Piday, 2018). For example, it is required for taking measurements, counting, timing, cooking, planning, and making decisions. Mathematics is also a body of knowledge that serves as the basis for science and technology (Anaduaka & Okafor, 2013), which means the problem of inadequate meaningful mathematical understanding is likely to continually affect students' performances in other undertakings.

Hence, in the Nigerian context, it is timely to consider effective pedagogical practices that facilitate students' mathematical understanding and replace the process of memorising procedural steps or algorithms just to pass examinations. In summary, the present study follows two pedagogical theories to explore effective pedagogies that could improve students' learning of mathematics in Nigeria.

Methodology

Present study

This study aimed to explore and compare the effectiveness of two pedagogical practices, *van Hiele teaching phases* and *cognitive load theory* (CLT) worked examples, on students' acquisition and understanding and retention of mathematical concepts. The study also aimed to determine the influence of pedagogical interventions on students' acquisition of conceptual and procedural mathematical knowledge. The existing literature provides empirical and theoretical evidence that both the van Hiele teaching phases and CLT worked examples improve students' mathematical performance (Abdullah & Zakaria, 2013; Armah et al., 2018; Ngu et al., 2019). Using this evidence, the investigation aimed to compare students' learning from the van Hiele teaching phases and CLT worked examples. Data from this research will contribute significantly to the formulation of recommendations for a more effective mathematics pedagogy, and also provide empirical evidence for the very few studies that use both quantitative and qualitative research designs in the Nigerian context. Hence, this study employed a mixed-method approach to provide evidence to support the few studies on the impacts of two seemingly contrasting pedagogical theories on students' understanding and solving of simultaneous linear equations.

Research design

The present study adopted a mixed-method research design with *in situ* treatments, denoted as X_1 and X_2. The use of both quantitative and qualitative approaches in this design provides a robust investigation and a better understanding of the research findings. Also, the design employed will create an avenue for wider generalisability of the research findings because the weakness of a single approach (quantitative) is complemented by the second approach (qualitative) (Bergman, 2011; Creswell & Creswell, 2018). Specifically, the study adopted a convergent design for mixed-method research, where both quantitative and qualitative data are collected concurrently to answer the research questions. However, the quantitative data have priority over the qualitative data, with the qualitative data being used to provide further exploration of the quantitative data.

This quasi-experimental study involved a 2×2×2 factorial research design of non-randomised and non-equivalent groups. This methodological design (for example, experimental treatment with data collected on multiple occasions) is appropriate from the perspective of social sciences, especially for the purpose of testing and inferring causal influences (MacCallum & Austin, 2000; Rogosa, 1979). Factorial designs are suitable when two or more independent variables are involved in a study design and are significant because they have the potential to determine individual experimental treatment effects, as well as potential interaction effects (Cohen et al., 2018). The dependent variable is the students' academic performance, understanding and retention while the independent variables are instructional methods (at two levels), students' ability (at two levels), and students' gender (at two levels). The experimental design is represented in Figure 1.

Time points	T_1		T_2	T_3
Experimental $group_1$	O_1	X_1	O_2	O_3
Experimental $group_2$	O_1	X_2	O_2	O_3

Figure 1: Experimental design

As shown in Figure 1, O_1 is the pre-test (T_1), O_2 is the post-test (T_2), and O_3 is the delayed post-test (T_3) for the experimental groups. X_1 and X_2 are the experimental interventions and ------- indicates the non-randomisation of the groups. In this case, three time-points of data collection would provide the basis for exploring growth trajectories (Bollen & Curran, 2006) and determining the extent to which an experimental treatment, X, could indeed have a lasting effect beyond T_2.

Proposed methodology before the pandemic

Prior to the pandemic that started in March 2020, the proposed plan for this research required the researcher to travel to Nigeria for data collection. The researcher would select, visit, and seek the permission of eight school principals to involve their students and mathematics teachers in the study. After permission was sought, four equivalent schools (with two schools randomly assigned to each experimental group) would be selected to participate in the study. The researcher would physically contact, invite, and recruit potential participants to the study in their various schools using information sheets and consent forms. It was hoped that 70 students and one mathematics teacher would be recruited from each school to have a total of 280 students and four teachers. The researcher would allow the students and their teachers to determine suitable times and class venues for the research activities. The research activities would be carried out in the students' classrooms and in the presence of their mathematics teachers, which would make students feel safe during the activities. The two instructional interventions would be carried out by the researcher, and each student would answer questions in pre-, post-, and delayed post-tests. However, outside of the experiments, it was proposed that five students from each ability group (high and low) would be randomly selected from each experimental group to attend interview sessions with the researcher. The interview questions aimed to elicit information on students' perception of the intervention. Furthermore, the four mathematics teachers would be required to complete a questionnaire about their perceptions of the intervention.

However, this initial, ethically approved plan could not be continued due to disruptions caused by the Covid-19 pandemic, in particular international travel restrictions. In addition, the current health and ethical guidelines do not support face-to-face contact with participants. All efforts to implement these interventions using online resources were abandoned because of the inadequate online facilities for teaching and learning in Nigeria. Hence, the method was reconceptualised to accommodate the current health safety instructions, ethical advice, and available resources.

Reconceptualised experimental design

In the reconceptualised methodology, the researchers sought the school's permission online and used previous networks to invite and recruit two mathematics teachers to the study. The mathematics teachers, with the assistant of a third-party teacher in the school, invited and recruited the students to the study. The mathematics teachers attended several *Zoom* meetings for training from the researchers on the intervention and procedure for data collection. Each mathematics teacher implemented an intervention with their students in their regular classes. The teachers gave feedback to the researchers after every contact and sought clarifications on issues. The interview initially planned for some selected students was redesigned into an open-ended justification for responses to the test questions. This serves as the qualitative data and helped to better understand students' thinking about solving simultaneous equations. The teachers' questionnaire was cancelled because researchers have had opportunities to receive feedback from the mathematics teachers during Zoom meetings. Also, the number of participants was reduced so that both the teachers and researchers would have a good control of the procedure. Generally, the researchers avoided face-to-face contacts with the participants and the mathematics teachers served as intermediaries between the researchers and the students. The details of the reconceptualised methodology are discussed next.

Samples

The sample for this research was 157 first-year senior secondary school students (Year 10) and two mathematics teachers in Ibadan, Nigeria. Ibadan is a city located in the southwestern region of Nigeria. It is the third most populous and largest city (geographically) in Nigeria (Sasu, 2022). The selection followed a purposive sampling technique (Cohen et al., 2018, p. 218-220). The researchers sought the permission of the schools to involve their teachers and students in the study. Five mathematics teachers were invited to the study using previous networks and relationships. Two teachers with at least five years' teaching experience and equivalent qualifications consented to be involved in the research. In Nigeria, there are two categories of schools: private or government-owned schools and single-gender or coeducational schools. This study involved government-owned schools because, according to the Nigeria Federal Ministry of Education (2017), 80% of Nigerian students attend schools owned by government, and therefore participants from government-owned schools can adequately represent the traits of all Nigerian students. Also, coeducational schools are appropriate as the study seeks to determine the influence of gender on students' mathematical understanding. Hence, only two government-owned, coeducational schools whose mathematics teachers and students agreed to participate in the study were involved in the research. Each school represented an experimental group.

Students' average age was 14 - 15 years, and the numbers of boys and girls were approximately equal. The students and teachers were bilingual, and English was the medium of instruction and the official language in schools, with students learning English as a compulsory subject from pre-school. The teachers reported that students were fluent English speakers with no problem writing, reading, and understanding English. Hence, this study was conducted in English. Students at the senior schools take either humanities, science and mathematics, business studies, or technology classes. Students' placement in a discipline is determined by their results in the external examination held in the previous year. This study considered students from only the science classes as their teachers reported they are the most competent in mathematics.

All state schools follow the state's Ministry of Education mathematics syllabus and mathematics textbooks; therefore, as confirmed by the mathematics teachers, all the participating students have been taught algebra and simple linear equations, which are pre-requisite topics for solving simultaneous equations. Also, the schools' locations meant that students shared similar cultural backgrounds, environmental differences, and equivalent mathematics learning prior to the data collection. The same sample size was used for both qualitative and quantitative data in order to retain consistency and avoid undue divergence of results.

Teachers' role

Two of the mathematics teachers were randomly assigned to an experimental group. Each teacher provided convenient times for Zoom meetings for training on the procedures for data collection, ethical issues, and intervention strategies. Each teacher attended five one-hour Zoom meetings with the researchers. The document for discussion was sent to the teachers' email addresses at least 48 hours before the scheduled time for them to read through before the meeting. Each teacher was scheduled to separate Zoom meetings with the researchers as they were to implement different interventions. The personal interaction with the researchers gave them more confidence, without intimidation, to interact and ask questions. During the meetings, the researcher explained the teacher's roles in each contact with the students, the likely problems, and the importance of communicating every piece of information related to the study. Overall, the teachers invited and recruited students to the study with the assistance of a third-party teacher, attended Zoom meetings with the researchers, administered the pre-tests, post-tests, and delayed post-tests to the students, implemented the intervention, and provided feedback to the researchers on issues impacting on the data collection.

Students' role

A third-party teacher (who usually had access to the students) provided the students with information sheets and sought consent from them and their parents to participate in the study. A third-party teacher was involved to invite and recruit students in order to resolve dependency or unequal relationship issues in recruiting participants (Cohen et al., 2018). The information sheets provided the reason for the research, the details of the student's roles, the voluntary nature of participation, the use of a pseudonym in the report, the benefits of participation, and the contact details of a local authority in case of complaints. After the recruitment process, only their mathematics teacher had face-to-face contact with the students. For this contact, normal school requirements for face masks and social distancing were followed.

The data were collected at three time-points. At the first time-point, students were given an identification number to use throughout the study, and a 40-minute pre-test (pen and paper) on solving simultaneous equations between 4 and 8 January 2021. The pre-test was administered to assess the students' knowledge baseline and understanding of solving simultaneous equations. The second time-point was the intervention, and involved administration of a post-test. The intervention phase required students to attend eight 40-minute lessons to learn how to solve simultaneous linear equations between 11 January and 3 February 2021. Each experimental group was taught the same content using either the van Hiele Teaching Phases or CLT worked examples. Immediately after the intervention, the students completed a post-test. The test was held immediately to minimise the risk of confounding effects (Morrison, 2012). The third time-point was a delayed post-test, administered to the students on 24 February 2021, which was three weeks after the intervention. It contained the same questions as the pre-test and post-test. The three-weeks delay helped to determine whether the effects realized during the post-test were sustained over time (Cohen et al., 2018).

The pre-, post- and delayed post-tests comprised nine open-ended, similar simultaneous equations problems and a section for students to justify the reasons for their answers. The items of the instruments have questions peculiar to both worked-examples instruction (where students are directed to use specific methods of solving simultaneous equations) and van Hiele teaching phases (where students could use any method of their convenience). These test instruments were validated by a professor, a senior lecturer, a lecturer, two teachers, all of whom are experts in mathematics education and the ethical committees. Their suggestions were incorporated into the final version of the instruments before data collection. Likewise, a Rasch analysis was used to establish the reliability of the instrument, with a 0.98 index before the intervention. The procedure for the data collection is outlined in Figure 2. It is important to note that the delayed post-test effects can not only be attributed to the intervention, but also to the student's retention ability and revision effect.

Intervention A – The van Hiele teaching sequence

This intervention followed the van Hiele Teaching Phases, which is a pedagogical strategy prescribed by the van Hiele theory (Van Hiele, 1986). This intervention occurred between January 11 and February 3, 2021 and consisted of eight 40-minute lessons. The first step was revision of linear equations, which is a pre-requisite for solving simultaneous equations. This revision lesson was necessary as a result of lack of schooling between April and November, 2020 caused by the pandemic lockdown. After the revision, students were taught how to solve simultaneous linear equations and contextual problems using the elimination, substitution, and graphical methods following the five teaching phases of the van Hiele theory: information, directed orientation, explication, free orientation, and integration. This sequence of teaching was followed throughout the teaching of simultaneous equations. It allowed students to gradually move from one thinking level to the next (Chew, 2009; Van Hiele, 1986).

At the information phase, the teacher questioned the students to assess their prior knowledge; then sets of sequenced activities were explored by the students and the teacher in the directed orientation phase. During explication, the students shared their explicit views and understandings of the activities of the directed orientation, and in the free

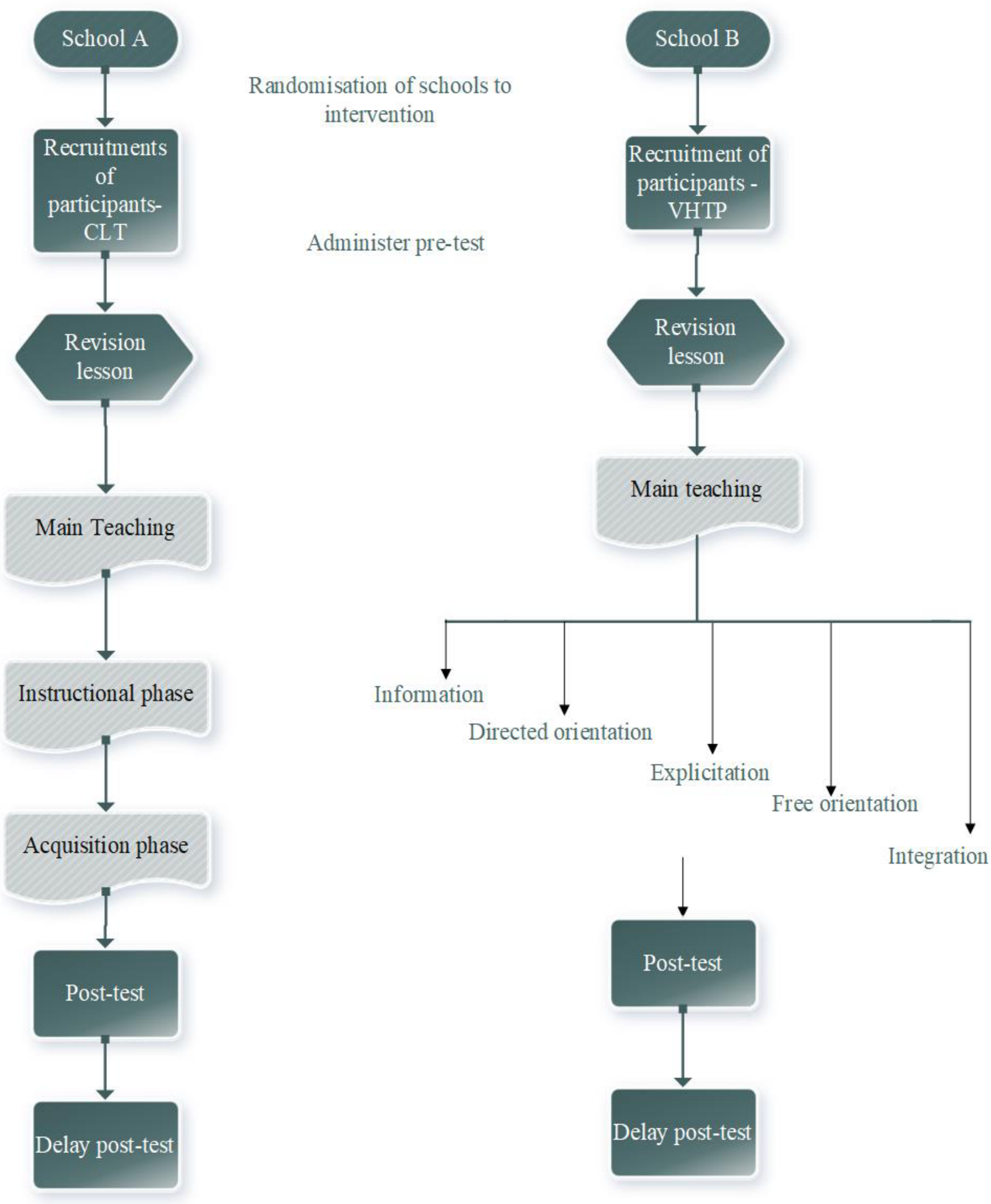

Figure 2: Flowchart of the data collection procedure

orientation phase, the teacher challenged the students to solve contextual problems related to simultaneous equations and make connections among the concepts. This stage is essential because students can demonstrate flexibility in their thinking, transfer learned materials to solve problems, and discover new knowledge that could help them to maintain an understanding of the interrelationships between concepts. Lastly, students reflected on the activities of solving simultaneous equations and how they fit overall to real-life problems (Serow et al., 2019).

Throughout this intervention, the teacher facilitated and stimulated students' emotional, intellectual and physical environment by exploring activities that led to solving the simultaneous equations. This exploration allowed the students to have a crisis of thinking, which helps them to build and demonstrate ownership of sound mathematical ideas through investigation and experience. Hence, students did not follow blind procedures leading to the correct answer. The interaction between the teacher and students in this intervention was similar to the gradual release of a responsibility instructional framework (Fisher & Frey, 2013), where the teacher mostly directs activities at the beginning and gradually shifts to student-directed tasks. The ideal and desired progression is from the 'information phase' which is mostly teacher-directed, to the 'integration phase' which is totally student-directed. Notwithstanding the shift in responsibilities, all activities remain student-centred. As the responsibility gradually shifts, students explore more activities, build confidence, and progress in their thinking of mathematical ideas from one level to the next. The student-teacher roles during this intervention are represented in Figure 3.

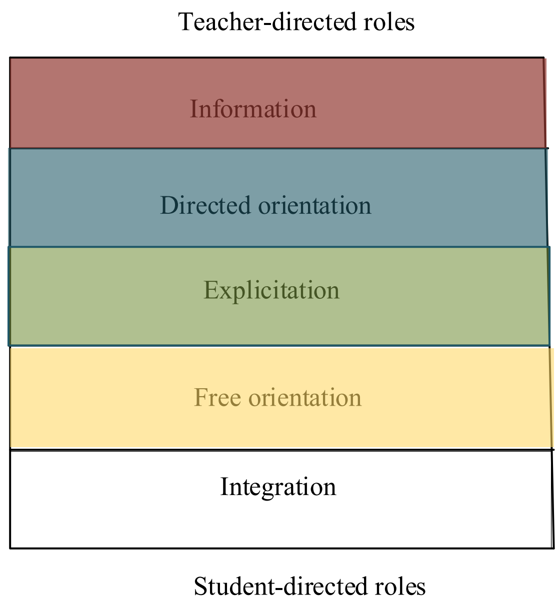

Figure 3: Teacher's shift of directedness with students during lessons

Intervention B – The CLT worked examples

This intervention, based on cognitive load theory (CLT) (Sweller, 2011), was assigned to the second experimental group to optimise students' understanding of simultaneous equations. Specifically, worked examples instruction was adopted. This intervention consisted of four major phases: revision phase, teaching phase, instructional phase, and acquisition phase. Previous studies on worked examples effects have combined only the instructional and acquisition phases to determine its effects. However, Ngu and Phan (2022) recently argued that worked examples would have an increased immediate and lasting effect on solving more complex linear equations if the revision and teaching phases are incorporated. From a CLT perspective, this approach would allow students to use their prior knowledge of simple equations to learn simultaneous equations, which reduces the cognitive demand required for learning. In addition, the data collection took place after students' learning was interrupted due to the seven-month lockdown. Therefore, the teacher revised simple linear equations with the students.

The initial lesson, which was the revision, addressed the pre-requisite knowledge for simultaneous linear equations to reduce the intrinsic cognitive load that is often associated with learning to solve simultaneous equations. After the revision lesson, the teacher taught the students how to solve simultaneous equations using substitution, elimination, graphical and word problems. The teacher followed a lesson plan that was designed by the researchers, which reflects sequencing of concepts related to solving simultaneous equations. Having attended the initial lesson and the main lesson, the students studied an instructional sheet on solving simultaneous linear equations. The instructional sheet comprised of definitions of different concepts and written procedures for solving simultaneous equations. The students also studied and completed an acquisition sheet, which consisted of eight example-problem pairs, two pairs for each method of solving simultaneous equations. As evident from the previous research, example-problem pairs of worked examples are more effective in facilitating schema than other forms of worked examples (Ngu et al., 2019; Van Gog et al., 2011). Each worked example has a similar practice problem. Students were instructed to study the worked examples before attempting equivalent practice questions.

From an instructional design perspective, the cues from the worked examples will help students to develop the schema required to solve both the practice and the post-test problems. The grasp of knowledge at this phase helps to reduce the mental effort that students use to solve related simultaneous equation problems because there is no crisis of thinking. Also, students still have access to the instructional sheet and can ask for help while solving the paired problems in the acquisition sheet (Ngu & Phan, 2016). The practice of solving similar paired problems following the cues of worked examples increases the procedural fluency of the students. With regard to the students' and the teacher's roles during the intervention, the teacher is active during the initial and main lesson while the students are active in the instructional and acquisition stages (Figure 4). Similar to the first intervention, this intervention was implemented over three weeks with eight 40-minute lessons.

Data analysis

The *Structure of the Observed Learning Outcomes* (SOLO) model was employed to score students' responses to the pre-test, post-test, and delayed post-test. The SOLO model was adopted because it considers both the qualitative and quantitative responses to judge students' understanding (Afriyani & Sa'dijah, 2018), ensures an objective assessment of students' cognitive growth, and identifies their levels of thinking (Adeniji at al., 2022).

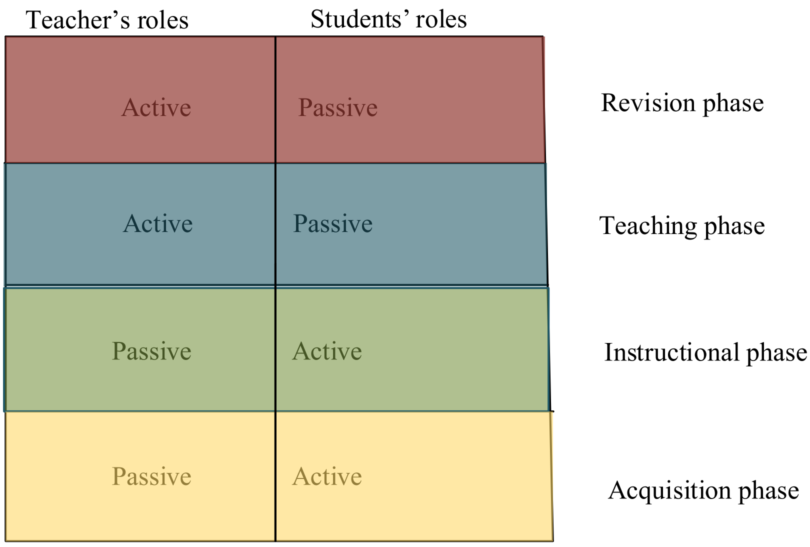

Figure 4: Students' and teacher's roles during intervention

The model consists of five modes of functioning and five levels of responses within each mode; however, the responses from this study were only relevant to two modes: concrete symbolic and formal modes. This is because the responses applied a system of symbols and abstract concepts to provide solutions to the simultaneous equation problems. Moreover, within the two SOLO modes relevant to this study, responses were described in six levels: pre-structural, unistructural, multi-structural, relational, formal mode 1, and formal mode 2. Students' responses were categorised such that the pre-structural responses were off-track, irrelevant, or no response at all; unistructural responses reflected an idea about the problem with no correct answer, such as labelling the simultaneous equations for easy identification; multi-structural responses had two or more disjointed relevant ideas and could not arrive at the correct answer due to confusion or getting stuck; and relational responses showed the interconnectedness between multiple ideas that led to the correct answer. Furthermore, formal mode 1 responses showed two or more connected ideas that transformed a word problem to simultaneous equations or uses a layman approach to solve contextual problems, while formal mode 2 advanced the responses of mode 1 by solving the simultaneous equations using acceptable mathematical approaches. Samples on the response categorisation based on SOLO model are given in the Appendix.

Accordingly, the responses were coded such that pre-structural = 0, unistructural = 1, multi-structural = 2, relational = 3, formal mode 1 = 4, and formal mode 2 = 5. A random selection of half of the students' responses to the nine tasks were used to establish reliability of the SOLO coding. An intra-rater reliability of 93% was obtained from the same SOLO level categorisation in the initial coding and subsequent coding. SOLO coding consistency was established through a sound understanding of the SOLO model and consultation with experts in SOLO model. The coded data that represented the quantitative data were then prepared for data analysis. The preparation included checking for missing data, verifying the outliers, creating an *Excel* spreadsheet for the data, transforming the variables, constructing *Winstep* files, and checking for the reliability index of the test instrument. The quantitative data were then subjected to an item-response theory for analysis. Item-response theory is suitable because students' abilities and item difficulties are placed on a single scale, which helps to determine learning progression and change in a student's abilities over time. This theory recognises the unequal difficulties of items in the test instrument, and therefore treats the responses of each item according to their difficulty index (Bond & Fox, 2013).

Specifically, the Rasch model, which is a psychometric model for analysing categorical data, was adopted to analyse the students' data, and *Winstep* software Version 4.8.2.0 was used for the analysis. This model is significant because it does not assume a linear rating scale (with equal intervals), and has its credibility in using a probabilistic approach of determining how the test instruments are functioning and relating individual item difficulty with students' ability (Engelhard Jr & Wang, 2021). The Rasch analysis was used to determine students' cognitive growth from pre-test to post-test and delayed post-test. To ascertain the significance of the growth recorded from the three time-points, the students' measures from the pre-test, post-test, and delayed post-test were imported into *Statistical Package for Social Sciences* (SPSS) and different descriptive and inferential statistics were carried out. Also, the influence of students' gender and students' ability on their learning was analysed at the 0.05 significance level. Likewise, the interaction between the instructional effects and students' gender and ability levels were examined.

Ethical considerations

The research followed the Australian *National Statement on Ethical Conduct in Human Research* (2007) and was unconditionally approved by the Human Research Ethics Committee of the University of New England, Australia. The schools in the region of interest were contacted for permission to access and engage their students and mathematics teachers in the research. A regular teacher in the school who would have nothing to do with the potential participants was invited to recruit students for the study to allow students absolute freedom of voluntary participation and to resolve the dependency issue of recruitment. All information, consent and assent forms were administered according to requirements as described previously. Students were fully aware that they could withdraw from participation at any stage of the study. Only students who gave assent after their parental consent were involved in the study.

In order to maintain students' confidentiality, they were assigned identification numbers that were used throughout the study. Participants were aware that any data obtained from them would be analysed and reported using a pseudonym. Consent for quoting anonymously was obtained, and there was no financial inducement provided for participation. Besides, to the best of the researchers' knowledge, transparency was ensured and all necessary information was disclosed to the participants.

No risk was identified for the participants in this study, except for inconvenience. To reduce the inconvenience, the students and teachers agreed on suitable times for the study. Also, the students are expected to feel safer participating in the research as they had their usual mathematics teacher. The students also had the opportunity to learn and develop their understanding of how to solve simultaneous equations using different methods and relate the mathematical ideas to real-life scenarios. For the teachers, there was benefit from the professional development provided by the research, as they were trained on research ethics, planning, and implementing a more effective and innovative pedagogy that is different from what they are used to. Lastly, the data obtained from the research were stored on the university's cloud and password-protected computers, according to the university's regulation on data management. As the data were collected in an overseas country, all the practices used throughout the conduct of this research were in line with the values of the Nigerian community.

Reflecting on the research methods

As mentioned earlier, the credibility of research findings depends on the methodology of the research. This section therefore reflects on the methodology employed in this research. This reflection scrutinises the adopted methodology in relation to its benefits and limitations. The study adopted multiple data sources to investigate the impacts of two pedagogical practices on Nigerian high school students' mathematical understanding. This mixed-method research type suggests a robust analysis of data that substantiates the generalisability of the research conclusions. Also, the intervention introduced to the participants strictly followed well-established theories of learning and instruction, which have both theoretical and empirical validations. Additionally, an objective assessment model (SOLO model) was followed to score students' qualitative and quantitative responses and minimise scoring bias. Moreover, the procedures for data gathering complied with the moral and ethical standards of the Nigerian community.

The benefits of this research methodology are numerous. First, it saves time, resources, and risk. As the researcher was unable to travel to Nigeria to collect the data due to the Covid-19 pandemic restrictions, the methodology was redesigned to accommodate the required health safety precautions and manage the available resources. This reconceptualised methodology saved the researcher the time, money, and stress involved in travelling to Nigeria and researching within schools. Second, even though Nigerian schools do not have adequate online facilities to help the researcher implement the instructional interventions remotely, the mathematics teachers have access to computers and the Internet. Therefore, the mathematics teachers were trained on how to collect the data, follow ethical regulations, and implement the pedagogical interventions. The training and experience in this research served as professional development for the teachers because they were exposed to more effective pedagogical practices that they can continue to use to teach other aspects of mathematics. Third, as the researchers did not want to overburden the teachers with interviewing their students, and to address any problems the students may have had with orally expressing their thinking about the completed tasks to the teacher, the interview was redesigned and merged with the test instruments, which require all students to share justification for their solution procedures. A suitable model was employed to score the responses simultaneously and place students' responses into increasing levels of thinking.

Fourth, by using a class cohort with their regular mathematics teacher, the participating students felt more comfortable during the interventions. In the same way, each teacher was scheduled to undertake separate Zoom meetings with the researchers, which helped them to feel less intimidated and free to speak about what is best for them and their students. Moreover, the students participating in the study were not exposed to any health risks because the face-to-face lessons with their teachers were carried out in their regular classrooms following the safety regulations prescribed by the Nigerian Ministry of Education. Lastly, the methodology used in this research was credible because teachers who are familiar and aware of their students' needs, performances, and abilities were directly involved and consulted for necessary information about the students. There were no identifiable risks imposed on the participants throughout the data collection process.

However, there are several limitations of this methodology. First, the researchers could not access students' non-verbal expressions during the data collection, such as communication through body language. Non-verbal communication is likely to direct the researchers to some salient points or issues that could help to provide more robust justification for the research findings. To address this issue, the researchers relied on students' responses and their reasons for completing the tasks. The researchers also relied on the teacher's feedback after every contact with their students. This may be a limitation to the research as compared to the pre-Covid research plan, where students could express their thoughts orally. Second, the researchers faced the challenge of the time difference between Australia, where the researchers reside, and Nigeria. This caused some personal inconveniences due to the researchers needing to conduct training for the teachers in the middle of the night via Zoom. At times, the teachers would be unable to keep their appointment times, so it would be necessary to cancel or postpone meetings to other times. Third, the number of participants was reduced so that researchers and teachers could have good control of the data collection process. However, the number of participants in the reconceptualised methodology was still large and valid for both qualitative and quantitative research. The fourth limitation was unstable Internet services, which occasionally disrupted Zoom meetings, often due to weather conditions, especially heavy rain events. Lastly, the methodology involves a potential threat to data privacy; however, the teachers had access to the data collected from their students only during the data collection phase. These data were scanned and sent to the researchers through email. After the scanning, the researchers confirmed that the data were complete and the teachers were required to destroy the hard copies of the data and delete the soft copies from their computer and their email records.

While this article focuses only on how an investigation was redesigned amidst covid-19 and the methodological approach employed, it is no doubt that readers may be curious about the results of this research. Despite travel bans arising from Covid-19, the redesigned methodology provided answers to the research questions, which determines and compares the impacts of worked-examples and van Hiele teaching phases on students' understanding of simultaneous equations. The adoption of the SOLO) model to classify qualitative and quantitative responses facilitate the understanding of the findings. In brief, the result of this investigation revealed that the van Hiele teaching phases are more beneficial to students' understanding (acquisition and retention) of simultaneous equations than the worked-examples instruction. Students' characteristics, such as ability levels and gender were also considered. Some details of the results have been presented by Adeniji and Baker (2022). In future research, the researchers hope to investigate teachers and students' views of the pedagogies adopted in this research.

This article was inspired by the researcher's passion for developing mathematics pedagogies in Nigeria and the limitations placed on research due to the current pandemic. Hence, it is strongly hoped that this article can encourage other international researchers, such as international students, to contextualise their study in their country while they are unable to travel there. In particular, the re-conceptualized methodology for gathering data in the Nigerian context has adequately utilized the available resources, health safety precautions, ethical standards, and ongoing regulations on lockdown to plan and collect reliable data that will help to achieve the research objectives. Given the outlined limitations of research during the pandemic, this investigation has employed strong pro-active procedures and methods that could be adopted for research in other developing countries with limited online facilities, similar to Nigeria.

Conclusion

This article outlined the research aims, methodology, and challenges of carrying out research in a pandemic-affected environment. This mixed-method research study was reconceptualised to balance the research aims and ethical standards with Covid-19 safety precautions. The research design considered adequate use of available resources, the need to follow Covid-19 precautions, and open-mindedness to methodological change. Due to the impacts of Covid-19 and the Nigerian context, the face-to-face data collection initially planned was reconceptualised to partial online data gathering. However, in order to not overburden teachers with the procedures for collecting the data, student interviews were replaced by an open-ended justification for the completed tasks and the teachers' questionnaire was cancelled. Data collection in a developing country during the pandemic and strict health regulations would have been impossible because of limited access to the Internet and online facilities required for teaching and learning.

Therefore, this article has explicitly discussed a revised procedure for data collection and provided justifications for individual methodological choices to establish the validity of the data gathered. In addition, reflection on the benefits and limitations of the re-conceptualised methodological approaches was provided. It is important to note that notwithstanding reconceptualisation, the method still followed ethical standards and answered the research questions appropriately. Fair recruitment, consent, information sheets, confidentiality, and other ethical issues were adequately addressed, all of which reinforced the validity of the methodology and the data gathered.

This research is significant because of the innovative methodological approaches designed to collect data in the context of developing countries such as Nigeria, and because it demonstrates how other researchers could adopt individual research approaches, quantitative, qualitative or mixed methods as used in this study, to continue their investigations during the pandemic. Importantly, as most international researchers are faced with very difficult situations for continuing their research, this article provides an insight into how to contextualise a study in their homeland, despite being unable to physically travel there. As the Covid-19 pandemic still lingers around the world with no certainty of eradication any time soon, future researchers could adapt and improve on this methodology to suit the context of their research.

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References

Abdullah, A. H. & Zakaria, E. (2013). The effects of van Hiele's phases of learning geometry on students' degree of acquisition of Van Hiele levels. *Procedia - Social and Behavioral Sciences*, 102, 251-266. https://doi.org/10.1016/j.sbspro.2013.10.740

Adeniji, S. M. & Baker, P. (2022). Comparative effectiveness of example-based instruction and van Hiele teaching phases on mathematics learning. In N. Fitzallen, C. Murphy, V. Hatisaru & N. Maher (Eds.), *Mathematical confluences and journeys*. Proceedings of the 44th Annual Conference of the Mathematics Education Research Group of Australasia. Launceston: MERGA, pp. 58-65. https://merga.net.au/common/Uploaded%20files/Annual%20Conference%20Proceedings/2022%20Annual%20Conference%20Proceedings/Research%20Papers/Adeniji%20RP%20MERGA44%202022.pdf

Adeniji, S. M., Baker, P. & Schmude, M. (2022). Structure of the observed learning outcomes (SOLO) model: A mixed-method systematic review of research in mathematics education. *EURASIA Journal of Mathematics, Science and Technology Education*, 18(6), article em2119. https://doi.org/10.29333/ejmste/12087

Adunola, O. (2011). *The impact of teachers' teaching methods on the academic performance of primary school pupils in Ijebu-Ode local cut area of Ogun State*. Ego Booster Books, Ogun State, Nigeria.

Afriyani, D., Sa'dijah, C., Subanji, S. & Muksar, M. (2018). Characteristics of students' mathematical understanding in solving multiple representation task based on SOLO taxonomy. *International Electronic Journal of Mathematics Education*, 13(3), 281-287. https://doi.org/10.12973/iejme/3920

Anaduaka, U. S. & Okafor, C. F. (2013). Consistent poor performance of Nigerian students in mathematics in senior secondary certificate examination (SSCE): What is not working. *Journal of Research in National Development*, 11(1), 1-5. [not found 8 Jan 2023]

Armah, R. B., Cofie, P. O. & Okpoti, C. A. (2018). Investigating the effect of van Hiele phase-based instruction on pre-service teachers' geometric thinking. *International Journal of Research in Education and Science*, 4(1), 314-330. https://eric.ed.gov/?id=EJ1169856

Awofala, A. O. A. (2017). Assessing senior secondary school students' mathematical proficiency as related to gender and performance in mathematics in Nigeria. *International Journal of Research in Education and Science*, 3(2), 488-502. https://eric.ed.gov/?id=EJ1148443

Bergman, M. M. (2011). The politics, fashions, and conventions of research methods. *Journal of Mixed Methods Research*, 5(2), 99-102. https://doi.org/10.1177/1558689811408318

Bollen, K. A. & Curran, P. J. (2006). *Latent curve models: A structural equation perspective*. Wiley. https://www.wiley.com/en-au/Latent+Curve+Models%3A+A+Structural+Equation+Perspective-p-9780471455929

Bond, T. G. & Fox, C. M. (2013). *Applying the Rasch model: Fundamental measurement in the human sciences*. Psychology Press. [4th ed.] https://www.routledge.com/Applying-the-Rasch-Model-Fundamental-Measurement-in-the-Human-Sciences/Bond-Yan-Heene/p/book/9780367141424

Chew, C. M. (2009). Enhancing students' geometric thinking through phase-based instruction using Geometer's Sketchpad: A case study. *The Asia Pacific Journal of Educators and Education*, 24(1), 89-107. http://apjee.usm.my/APJEE_24_2009/JPP24_06_ChewCM_89-107.pdf

Cohen, L., Manion, L. & Morrison, K. (2018). *Research methods in education* (8th ed.). https://www.routledge.com/Research-Methods-in-Education/Cohen-Manion-Morrison/p/book/9781138209886

Creswell, J. W. & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches*, 5th ed. SAGE Publishing. https://us.sagepub.com/en-us/nam/research-design/book255675

Engelhard Jr, G. & Wang, J. (2021). *Rasch models for solving measurement problems: Invariant measurement in the social sciences*. SAGE Publishing. https://us.sagepub.com/en-us/nam/rasch-models-for-solving-measurement-problems/book267292

Federal Ministry of Education (2017). *Nigeria Digest of Education Statistics 2014-2016*. https://education.gov.ng/nigeria-digest-of-education-statistics-2017/

Fisher, D. & Frey, N. (2013). *Better learning through structured teaching: A framework for the gradual release of responsibility*. ASCD. [3rd ed.] https://www.ascd.org/books/better-learning-through-structured-teaching-a-framework-for-the-gradual-release-of-responsibility-3rd-edition?variant=121031

Khalid, M. (2006). Mathematical thinking in Brunei curriculum: Implementation issues and challenges. In *Proceedings APEC-TSUKUBA International Conference*. Tokyo. pp. 169-178. https://www.criced.tsukuba.ac.jp/math/apec/apec2007/progress_report/specialists_session/Madihah_Khalid.pdf

Kolawole, E. B. & Ojo, O. F. (2019). Effects of two problem solving methods on senior secondary school students' performance in simultaneous equations in Ekiti State. *International Journal of Current Research and Academic Review*, 7(1), 26-31. https://doi.org/10.20546/ijcrar.2019.701.003

MacCallum, R. C. & Austin, J. T. (2000). Applications of structural equation modeling in psychological research. *Annual Review of Psychology*, 51(1), 201-226. https://doi.org/10.1146/annurev.psych.51.1.201

Magen-Nagar, N. (2016). The effects of learning strategies on mathematical literacy: A comparison between lower and higher achieving countries. *International Journal of Research in Education and Science*, 2(2), 306-321. https://eric.ed.gov/?id=EJ1105113

Morrison, K. (2012). Searching for causality in the wrong places. *International Journal of Social Research Methodology*, 15(1), 15-30. https://doi.org/10.1080/13645579.2011.594293

National Statement on Ethical Conduct in Human Research (2007). Australian Government. https://www.nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018

Ngu, B. H. & Phan, H. P. (2016). Comparing balance and inverse methods on learning conceptual and procedural knowledge in equation solving: A cognitive load perspective. *Pedagogies: An International Journal*, 11(1), 63-83. https://doi.org/10.1080/1554480X.2015.1047836

Ngu, B. H. & Phan, H. P. (2022). Learning linear equations: Capitalizing on cognitive load theory and learning by analogy. *International Journal of Mathematical Education in Science and Technology*, 53(10), 2686-2702. https://doi.org/10.1080/0020739X.2021.1902007

Ngu, B. H., Phan, H. P., Sigauke, A. T., Maniam, V. & Usop, H. (2019). Cognitive load on learning one-step equations: A cross-cultural study between Australia and Malaysia. *Current Politics and Economics of South, Southeastern, and Central Asia*, 28(1), 103-130.

Nigerian Educational Research and Development Council (2004). *National policy on education. 4th ed.* http://wbgfiles.worldbank.org/documents/hdn/ed/saber/supporting_doc/AFR/Nigeria/TCH/National%20Policy%20on%20Education.pdf

Nigerian Educational Research and Development Council (2014). *Basic education (Primary 1-3).* NERDC e-Curriculum Portal. http://nerdc.org.ng/eCurriculum/CurriculumStructure.aspx

Omobude, E. O. (2014). *Learning mathematics through mathematical modelling: A study of secondary school students in Nigeria*. MEd thesis, Universitet i Agder, Norway. http://hdl.handle.net/11250/222317

Piday (2018). *Why is math important in life?* Mometrix. https://www.piday.org/10-reasons-why-maths-is-important-in-life/

Rogosa, D. (1979). Causal models in longitudinal research: Rationale, formulation, and interpretation. In J. R. Nesselroade & P. B. Baltes (Eds.), *Longitudinal research in the study of behavior and development*, 263-302. New York: Academic Press.

Sasu, D. D. (2022). Largest cities in Nigeria. *Statista*, 5 December 2022. https://www.statista.com/statistics/1121444/largest-cities-in-nigeria/

Serow, P., Callingham, R. & Muir, T. (2019). *Primary mathematics: Capitalising on ICT for today and tomorrow.* 3rd ed. Cambridge University Press. http://www.cambridge.org/9781107688124

Sweller, J. (2011). Cognitive load theory. In B. Ross (Ed.), *Psychology of learning and motivation* (Vol. 55, pp. 37-76). Elsevier. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Ugboduma, O. S. (2012). Students' preference of method of solving simultaneous equations. *Global Journal of Educational Research*, 11(2), 129-136. https://doi.org/10.4314/gjedr.v11i2.8

Van Gog, T., Kester, L. & Paas, F. (2011). Effects of worked examples, example-problem, and problem-example pairs on novices' learning. *Contemporary Educational Psychology*, 36(3), 212-218. https://doi.org/10.1016/j.cedpsych.2010.10.004

Van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education.* Academic Press.

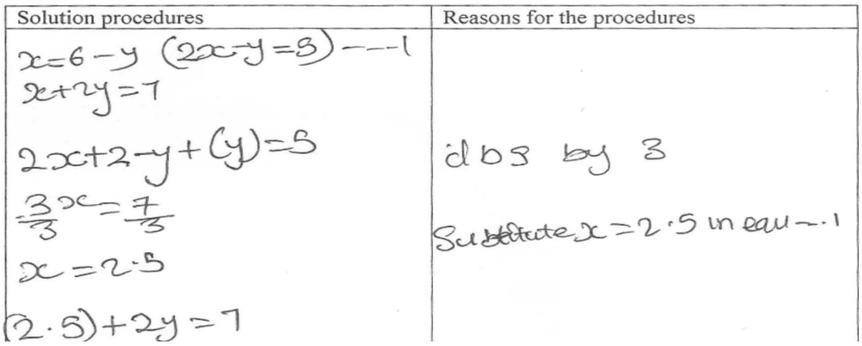
Wellington, J. J., Bathmaker, A., Hunt, C., McCulloch, G. & Sikes, P. (2005). *Doing research: Reflection on methods, methodology and ethics*. SAGE Publications. https://doi.org/10.4135/9781849209977

Appendix: Samples of response coding according to SOLO model

Sample of a pre-structural response

The solution is totally off-track.
QUESTION: Solve the pair of simultaneous equations using the substitution method and explain each step of the answer using the space provided.

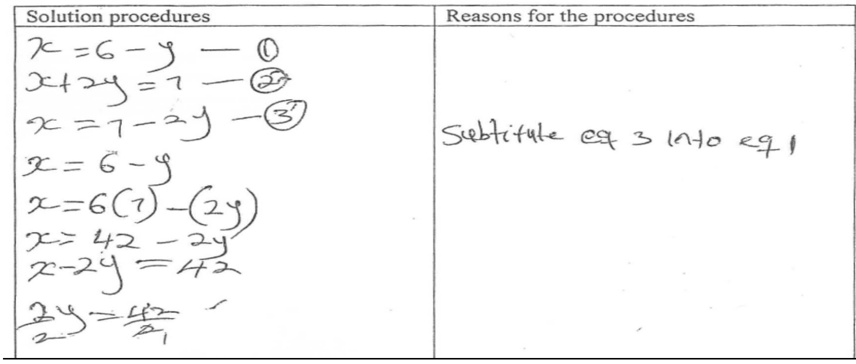
x = 6 – y
x + 2y = 7



Solution procedures	Reasons for the procedures
$x=6-y$ $(2x-y=3)$ ---1	
$x+2y=7$	
$2x+2-y+(y)=5$	dbs by 3
$\frac{3x}{3}=\frac{7}{3}$	Substitute $x=2\cdot5$ in equ--1
$x=2\cdot5$	
$(2\cdot5)+2y=7$	

Sample of a unistructural response

This response only indicates an idea of numbering the equations for easy identification.
QUESTION: [see above]



Solution procedures	Reasons for the procedures
$x=6-y$ — (1)	
$x+2y=7$ — (2)	
$x=7-2y$ — (3)	Substitute eq 3 into eq 1
$x=6-y$	
$x=6(7)-(2y)$	
$x=42-2y$	
$x-2y=42$	
$\frac{2y}{2}=\frac{42}{2}$	

Sample of a multi-structural response

The response contains two or more relevant ideas towards the solution of the equations but mixed-up things and did not arrive at the correct answer.

QUESTION: [see above]

Solution procedures	Reasons for the procedures
$x = 6 - y$	equation 1
$x + 2y = 7$	equation 2
from equation (1) $x = 6 - y$	equation 3
$x + 2y = 7$ $x = 6 - y$	Substitue eq 3 into (2)
$6 - y + 2y = 7$ $x = 6 - (-1)$	Substitue $y = -1$ into eq 3
$6 - y = 7$ $x = 6 + 1$ $-y = 7 - 6$ $x = 7$ $\frac{-y}{-1} = \frac{1}{-1}$ $y = -1$	$\therefore x = 7, y = -1$

Sample of relational response

Response used several ideas with appropriate justification to solve the equations and find the correct answers.
QUESTION: [see above]

Solution procedures	Reasons for the procedures
$x = 6 - y$ ←—— (i) $x + 2y = 7$ ←—— (ii) $y = 6 - x$ $x + 2(6 - x) = 7$ $x + 12 - 2x = 7$ $x - 2x = 7 - 12$ $-x = -5$ ~~$x = -5$~~ $x = 5$ $5 + 2y = 7$ $2y = 7 - 5$ $\therefore x = 5$ and $2y = 2$ $y = 1$ $y = 2/2 = 1$	make y the subject of the formular, ~~so~~ there fore any where you see y, the y will be $6 - x$ After gotten x which 5, you have to substitute $x = 5$ in eqn 2. $\therefore x = 5$ and $y = 1$

Sample of formal mode 1

Response reflects an approach to the solution with no sophisticated mathematical approach and correct answers were not found.
QUESTION: A supermarket sells noodles and spaghetti. 2 noodles and 2 spaghetti cost #70. 4 noodles and 3 spaghetti cost #120. What is the cost of one noodle and one spaghetti?

---

3 spaghetti and 4 noodles = ₦120
2 noodles and 2 spaghetti = ₦70
one noodles and one spaghetti = The total value of 2 noodles and two spagh divided by 2

$= \frac{70}{2} = 35$

∴ one noodles and one spaghetti = ₦35

Sample of formal mode 2

Response depicts several examples of formal thinking about forming mathematical equations from the problem and using a mathematically acceptable method to find the correct answers with appropriately justified reasons blended to the solution procedure.
QUESTION: [see above]

Let noodles be represented with the letter (a) and Spaghetti letter (b)

$2a+2b = 70$ --- (i) (×2)
$4a+3b = 120$ --- (ii)

$4a+4b = 140$ --- (iii)
$4a+3b = 120$ --- (iv)

Subtract eqn (iv) from eqn (iii)

$4a - 4a + 4b - 3b = 140 - 120$
$4b - 3b = 20$
$b = 20$

Substitute 20 for b in eqn (i)

$4a+3b = 120$
$4a+3(20) = 120$
$4a+60 = 120$
$4a = 120-60$
$4a = 60$

Divide both sides by 4

$\frac{4a}{4} = \frac{60}{4}$
$a = 15$

∴ a = 15 and b = 20
∴ 1 noodle = # 15 and 1 Spaghetti = # 20

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