An Account of the Methodological Implementation of Design-Based Research in the Chemistry Classroom Context

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Abstract

Design-Based Research (DBR) has recently received a significant amount of attention in the educational research literature of the 21st century. This work analyses the understanding of DBR as the research methodology, why, and how it can be applied in educational research to bring a practical outcome and improve educational practices. Besides, this work reflects on a step-by-step implementation of the Hands-on Instructional Model (HIM) designed to enhance the development of chemistry learners' curiosity and problem-solving skills. Also, it gives a detailed description of the two prototypes of the first alteration cycle. A sample of 169 Senior Three chemistry students was purposively selected from three science classes to participate in this study. Design-based research was recommended as a viable research methodology to educational researchers for their lifetime professional contribution to the research in the education field and to bridge the gap between theory and practice in educational contexts.

Keywords: Design-Based Research, Educational Research, Methodology, Practice, Theories

Introduction

Tanzania has been implementing vision 2025 in the recent decade (URT, 2014) which highly emphasizes the provision of quality and productive education. According to (Kalolo, 2015), quality education should enable students to acquire consistent experience from the teaching and learning process. The provision of quality education should consider approximate proportionality between available resources and the growing population (Haki Elimu, 2013; URT, 2014). This implies that the rise in population also requires subsequent expansion of the education system. Besides, there have been calls for science education research to invert theories and methodologies that perpetuate the provision of quality education (Bakker & van Eerde, 2015; Bozkurt Altan & Tan, 2020). These calls include the recommendations that researchers should ground their work in Design-Based Research. DBR is considered to be a complex system of research that highly advocate interaction among researchers, students, instructors, and environmental component (Scott et al., 2020; Zhao et al., 2021).

Design-Based Research emerged as a reaction to suppress the failure of some traditional research methodologies to link theory and practice within an educational context (Alghamdi & Li, 2013; Bakker & van Eerde, 2015). However, DBR is worth generating significant knowledge to guide educational practice (Collective, 2003; Parker, 2011; Wang & Hannafin, 2005).

The purpose of DBR is to formulate interventions that inform educational practice through theoretical frameworks (Brown, 1992). According to Wang and Hannafin (2005), researchers accomplish research processes in collaboration with participants, design and systematically implement interventions. The interventions serve to refine and improve the preliminary designs and ultimately seek to advance both pragmatic and theoretical purposes that may be affecting practice (Carstensen & Bernhard, 2019; Gutiérrez, 2018). Cobb et al. (2003) and O'Donnell (2004) highlighted that DBR speaks directly to a problem of educational practice that can lead to the formulation of usable knowledge. In this regard, DBR is a vital research methodology that should be taken into consideration by educational researchers so that to minimize the gap between theory and practice.

This work aims at the contextualization of DBR in a chemistry classroom setting by giving a brief description of design-based research as a suitable research methodology for science education researchers. The description of DBR in this research work is complemented with a fieldwork research design of an intervention done to develop learners' curiosity and problem-solving skills through hands-on activities in chemistry lessons using instructional materials designed by learners from their immediate environment. Therefore, the emphasis of this work is focused on educational research for improving practices by solving problems in the educational context.

Meaning of Design-Based Research

Design-based research has been defined differently by various scholars depending on the context and different perspectives. According to Wang and Hannafin (2005), DBR is "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" (p. 6-7). Also, Barab and Squire (2004) defined DBR as a sequence of approaches, with the determination to produce new artefacts, theories, and practices that potentially impact learning and teaching in a naturalistic setting.

However, Brown (1992) and Collins (1992) argued that DBR is an emerging model for the studies of learning context through a logical design and study of instructional tools and strategies. Therefore, with the multiple conceptualization and definitions of DBR, it is concluded that a better description of it should explain briefly the context and process through which a design is formulated, tested, and applied to produce theories and principles that can improve educational practices.

Various research designs have been suggested including surveys, case studies, experiments, action research, ethnography, correlational research, evaluation research, and design research (Creswell, 2014; Mertens, 2010; Migiro & Magangi, 2011). Some of these research designs have some commonalities with design-based research. Andriessen (2008), mostly associated design-based research with experiments and action research. He argues that DBR is the intermediate research design between quasi-experiment and action research types of intervention. According to Collective (2003) and Hoadley (2004), Design-Based Research is a complement to experimentation. Nonetheless, the description of these comparisons is shown in **Table 1 below**.

Table 1: Comparison between design-based research with experimental and action research

Research Design	Literature	Similarities with DBR	Differences with DBR
Quasi-experiment and Experimental research	Bannan-Ritland (2003); Bowler and Large (2008); Collective (2003)	Both considered as intervention research	No control group in design-based research while in experimental research compare groups
Action research	Alghamdi and Li (2013); Andriessen (2008); Collective (2003); Wang and Hannafin (2005)	Both design and develop a solution to a practical problem	In action research, the practitioner initiates the research and the researcher facilitates the research process while in design-based research, researchers usually take the initiative as both researchers and designers.

The Rationale of Using DBR

The major purpose of DBR is generally to “address complex problems in educational settings” (Sari & Lim, 2012, p.2) to create a stronger connection between educational research and real-world problems (Alghamdi & Li, 2013; Scott et al., 2020). Furthermore, the outcome of DBR leads to the improvement of educational practice in the real-world setting of similar environments. Alghamdi and Li (2013) pointed out that DBR researchers are expected to generate from a particular design, evidence-based claims about learning that address contemporary theoretical issues and further add the theoretical knowledge in the field of education. In conceptualizing the purpose of DBR, it is strictly important to identify DBR from other traditional research methodologies. “Central to this distinction is that design-based research focuses on understanding the messiness of real-world practice, with the context being a core part of the story and not an extraneous variable to be trivialized” (Barab & Squire, 2004, p.3). Therefore, based on the focus of this research project it was worth employing DBR to achieve the expected outcome of the designed intervention in the context of community secondary schools in Tanzania.

Methodology

Application of DBR in the Context of this Research Project - Intervention

This section describes how DBR was employed to develop an intervention on hands-on activities to enhance learners’ curiosity and problem-solving skills in chemistry lessons. The main output of the methodological implementation of DBR in this study is the outstanding Hands-on Instructional Model (HIM) which operates in the activity-based classroom environment. Besides, all the activities performed during the intervention were to enable students become independent learners who can explore the environment, work with the appropriate instructional materials, and grasp the underlying concept well.

The Setting and Research Participants

This study was conducted in three community secondary schools in Dar es salaam, Tanzania. Dar es Salaam comprises 142 public secondary schools where 132 schools are community secondary schools. The target population comprised of both students and teachers. A total number of 169 Senior Three students, 60% boys and 40% girls within the age ranging between 15 and 17 were purposively selected from three intact science classes. These students had a mean age of 16.12 and a standard deviation of 0.854. The implementation of this study was facilitated by three teachers (two female and one male) with an average teaching experience of five years. Senior three is the third year of the Ordinary Level of secondary education according to the Tanzanian education system.

Materials

The activities were conducted in authentic, real-world classroom sessions where both students and teachers in chemistry lessons were involved in these activities. Initially, before implementation of the designed intervention teachers were teaching using the prepared lesson notes and textbooks only. Students' involvement in the lesson activities was non-existent and teachers were the chief controller of the lesson. Besides, the materials used to make the instructional materials were obtained from students' surroundings such as school and home, but the content facilitated was from mole concept and volumetric analysis of the senior three syllabuses.

Data Collection

Data was collected in form of a convergent mixed method (Creswell, 2014) using both qualitative and quantitative approaches (QUAL + quant). The data obtained included the field observation schedules, interviews, and Focus Group Discussions (FGDs) audio-recorded data, field notes, teachers' reflections as well as Teacher Rating Scale (TRS), Students Self-Reporting Questionnaire (SSRQ), and Problem-Solving Test (PST) results. The triangulation method was used to interpret and check for the accuracy of the information obtained from all research instruments. **Table 2 below** gives a detailed methodological matrix of these instruments including the frequency of data collection for each instrument, and the purpose.

Table 2: Methodological matrix of the research instruments and their corresponding purpose

Tools	Number(s)	Rationale/purpose
Lesson observation Protocol	42 lessons were observed	-Teachers and students in chemistry lessons -students making instructional materials on

		their own in chemistry lessons -Students manipulating the instructional materials in chemistry hands-on activities
Face to face semi-structured interview guide	21 interviews from the three schools	-To obtain enough information from audio recording and field notes from teachers based on the implementation of the designed intervention
Face to face semi-structured FGD guide	21 FGDs from students in the three schools	-To obtain information from students regarding the intervention designed to facilitate their learning and acquisition of basic learning skills like curiosity and problem-solving skills
Curiosity SSRQ	Twice (before and after the intervention	-To quantify learners' curiosity developed from the learners perspective
Curiosity TRS	Twice (before and after the intervention)	-To quantify learners' curiosity developed from the teachers perspective
PST	Twice (before and after the intervention)	-To obtain quantified information on the development of problem-solving abilities

Steps of DBR in this Research Project

The implementation of DBR in this research study was done in the classroom settings specifically in chemistry lessons. All the lesson activities were done under the facilitation of the teachers using a Competency-Based Curriculum (CBC) and a Senior Three chemistry syllabus. Also, the study followed a pragmatic philosophical view and (Reeves, 2000)'s four steps of implementing DBR. The four steps by Reeves were preferred because they fit the context, purpose, and focus of this research project, which is basically to inform practice through the development of a Hands-on Instruction Model.

The first HIM prototype was proposed by the researcher and the teachers then tested in the classroom context to the group of the selected students. It was refined further to another prototype which was implemented again to the same group of students to strengthen its effectiveness and efficiency. The four steps which involved the development and implementation of the HIM prototypes are briefly described in **Figure 1 below**.

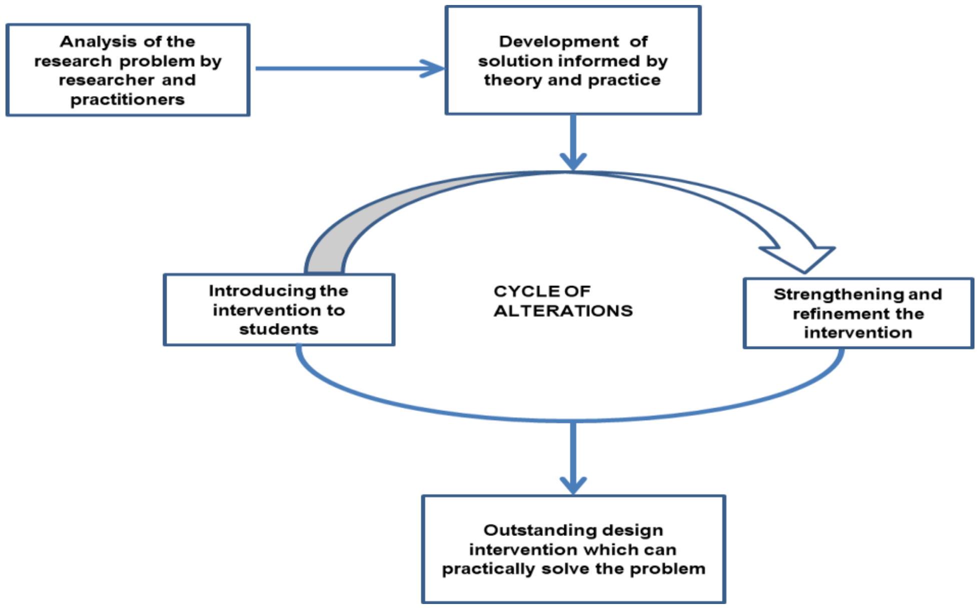

Figure 1: A DBR model designed to guide the study

Step 1: *Analysis of the Research Problem*

Initially, one of the researchers did a comprehensive literature review based on the research problem at hand and shared the insights with the other two researchers. The comprehensive literature review by the researchers gave some preliminary information on the research problem. Again, the information obtained about the problem was then collaboratively shared with three Ordinary Level chemistry teachers in Dar es salaam, Tanzania by one member of the researcher team. The other two researchers played part in the rating process, analysis, and write-up preparations. In addition, the three teachers were the active participants in the study although the primary participants were the students. The collaborative discussions between the researcher and the teachers enhanced the invention of the first HIM prototype which was proposed as a solution to the identified research problem in form of an intervention design.

The research problem was to work on a practical solution that can enhance students' curiosity and problem-solving skills during chemistry lessons hands-on activities performed using instructional materials designed by learners. We both brought ideas from literature and teaching experience on the better way that learners could design instructional materials. Therefore, the proposed HIM prototype was thought to bridge the gap between the acquisition of the identified skills and the insufficient instructional material.

Step 2: *Development of the First HIM prototype Informed by Pragmatic and Zone of Proximal Development- ZPD Theories and Practice*

The collaborative discussion between the researcher and the three chemistry teachers was done in three days of orientation guided by pragmatic and ZPD theories. However, the fact that students learn through their experiences posited by John Dewey in pragmatic theory drew our attention to meet the purpose of this study. According to John Dewey, the experiences brought by learners in classroom situations from the outside environment can influence their learning (Sikandar, 2016). Also, the generation of knowledge occurs in real and meaningful situations, through natural activities done by students (Rizk, 2011).

However, Lev Vygotsky specified that learners' experiences are polished in the Zone of Proximal Development (ZPD) (Fani and Ghaemi, 2011; Lui, 2012), in presence of a mentor or capable peer (Fani and Ghaemi, 2011). The main idea in ZPD is that students can learn better when there is collaboration with others or when they are well guided by the teachers. Such shared endeavours with a more experienced person depict that learners learn better and assimilate new concepts, and skills through collaborative learning (Fani and Ghaemi, 2011; Glassman, 2001; Lui, 2012). Thus, the two theories gave insights on how learners can bring experiences in the class; collaboratively share with other peers under teacher guidance to bring meaningful learning.

The information obtained from the two theories was collectively combined with the views provided by the chemistry teachers to plan for the procedures that guided the intervention. Also, teachers were taken through the orientation on how to involve hands-on instructional strategy in their chemistry lesson sessions. The major task of the teachers during the intervention was to facilitate the process of learning including guiding students in hands-on activities and ensuring that appropriate instructional materials are made by learners. Also, the teacher had to ensure that the equipment made by learners is from their immediate environment. Therefore, the teachers contributed the knowledge on the designed intervention for it to bring about tangible, realizable, and significant outcomes.

After the orientation, the designed HIM prototype was implemented in the three selected intact science classes and the project ideas were introduced to the chemistry students. In addition, students were given guidelines on searching and preparing the appropriate instructional materials that could facilitate the learning of the selected topics. Teachers shared the criteria and the learning intentions which are the objectives of the lesson. The objectives were shared at the beginning and the end of every lesson. The shared objectives of the lessons enabled students to think of the materials that could best be used to make appropriate and relevant instructional materials that correspond to the content to be learned. However, some of the materials made by students were used to measure some particular quantities in the mole concept, and others were used for titration purposes.

At the beginning of the intervention, teachers guided students on the materials that could be used to design the appropriate instructional materials. For instance, in preparation for the lesson about the link between the mole and other units, the teachers instructed students to bring materials such as rulers, coins, sand, water, salt, and other materials that can represent units in distance, kilograms, pairs, dozens, and time. Also, students prepared some apparatus from home-based materials that were used in titration experiments of volumetric analysis. Some of the apparatus prepared by students included beakers, burettes, pipettes, funnels, measuring cylinders, droppers, and retort stands. Below are the illustrations of how some apparatus were prepared by the students.

Beakers

Beakers were made nearly in the same way as measuring cylinders although for the beakers empty water bottles were cut into different sizes. Then, water was measured using commercially produced beakers of different capacities and transferred into empty water bottles. Students used white papers and permanent markers to mark the calibration of different volumes such as 50 mils, 100 mils, and 200 mils on the sides of the bottles.

Figure 2: locally made beakers of different sizes

Burettes

The burettes were prepared by using new clinical syringes, plastic rubber tubes, ball pen tubes, and glue. 3 or 4 syringes were cut and glued together to make the top part of the burette with calibration to which a transparent ball pen tube was joined with a plastic rubber tube to complete the making of the burettes. Then, a peg was put in between the plastic rubber tube to control the flow of reagents from the burette. The burettes prepared were used to regulate titter values for the acid solution in simple titration experiments. It should be noted that the idea of using the syringe to make the burettes was brought by a few students who accessed the syringes through their parents who are medical attendants. Other syringes were purchased and distributed to other students who could not access them for free to maintain uniformity of the materials used by all students.

Pipettes

For the pipettes, transparent plastic tubes of different sizes were cut and ball pen tubes were glued at the upper and lower parts of the plastic tube. Then, water was measured using commercially made pipettes of different capacities and put into locally made pipettes, and calibrated by marking different volumes such as 20 and 25 mils on the pipettes. The pipettes prepared by students measured the volume of alkaline solution in the titration experiments.

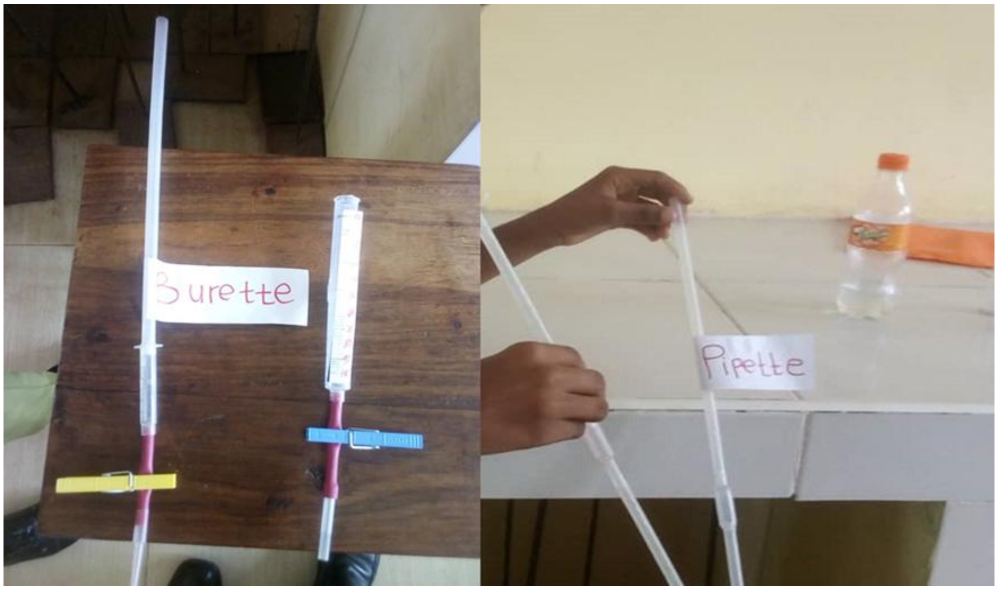

Figure 3: locally made burette and pipette

Manipulation of the Instructional Materials

The manipulation of the locally made instructional materials was done in groups and students shared responsibilities equally under the guidance of their teachers. Students managed to make the apparatus but it was challenging for them to bring in the class simple chemicals from home-based materials which could appropriately be used during the titration process using the locally made apparatus. Perhaps, due to the limited time that the intervention was supposed to last, students could not explore more the environment to obtain simple chemicals from home-based materials. Teachers prepared standardized chemicals to complement the students' efforts and simple titration procedures were successfully done in the chemistry lesson sessions. Also, the preparation of apparatus like measuring cylinders, beakers, droppers, and funnels was easier than burettes, pipettes, and retort stands because they require many materials and procedures as well as proper calibration of volume to ensure accuracy of the measurements of these apparatus. Lastly, the designed apparatus were drawn on sheets and hung on the war in chemistry lessons to enable easy identification and memorization.

Step 3: *Cycle of Alteration*

The processes in step 2 were successfully done in two phases whereby after each phase, the evaluation was done to make some adjustments to the prototype implemented in the intervention process. The evaluation was done based on the analysis of the data collected from field notes, lesson observation, FGDs, and the teacher interviews, curiosity SSRQ, curiosity TRS as well as PST. This is to say, the information obtained from the daily analysis of data from Phase I informed Phase II.

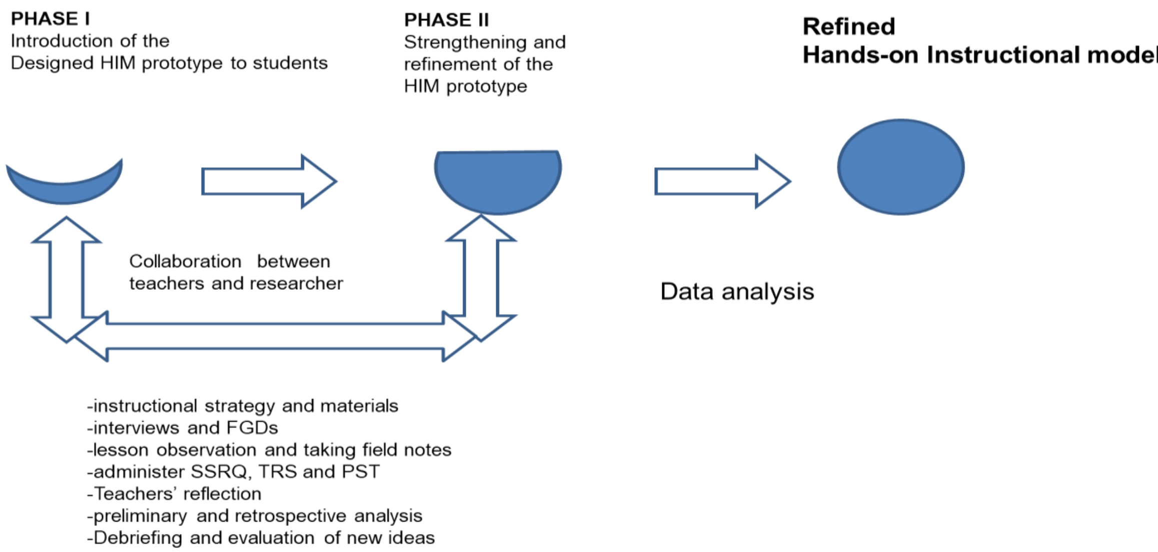

Figure 4: Description of the circle of alteration

The information obtained was briefly shared among the three teachers who were involved in this study to reduce the variation in the outcome from the intervention especially on students' active participation in hands-on activities, curiosity, and problem-solving skills. Excluding data analysis which was done by the researchers, the evaluation of the evolvement of the intervention was done by both the teachers involved in the study and the researchers.

Step 4: *Analysis and Reflection on the Data from the Intervention and the Implementation of the HIM prototypes.*

Refinement of the intervention continued throughout until when saturation was attained. Students' engagement in hands-on and mind-on activities was continuously monitored until when they became accustomed to the process of intervention. However, positive outcomes from the intervention were noted through students' actions and behaviour, as well as the analysis, which was done on the instructional strategy and materials, interviews and FGDs, lesson observation and field notes, SSRQ, TRS, PST, and Teachers' reflections. Students continued to work in their groups and cooperated in searching for instructional materials that were deemed to be appropriate to the content learned.

Daily analysis of the data was done in two forms: preliminary and retrospective analysis. The preliminary analysis was performed on the teachers' reflections, SSRQ, TRS, and PST results to obtain the required information. Also, the retrospective analysis was performed continuously on the information obtained daily from lesson observation, field notes, and the audio recorded information from interviews and FGDs for the continuous refinement of the intervention. Finally, the overall analysis was done to the bulky bunch of data collected from the whole process to obtain the concrete information which can be used to justify the viability of the hands-on DBR model designed.

Discussion

In the first PHASE of the cycle of alteration where the HIM prototype was first introduced to students, the following key findings emerged which resulted in some refinement of the designed intervention:

(a) the act of both teachers and students being involved to bring the materials to make the desired instructional materials could not result to the intended research outcome. This made students be sluggish and rely on the materials that were only brought by the teachers;

(b) Students' involvement in making the instructional materials as a whole class also made some students dodge from the process and leave the burden to few students who were responsible;

(c) When the intervention began, most of the students used much of the lesson time to make the instructional material. Therefore, some adjustments were made to ensure the intended outcome of the intervention and the implementation of the entire DBR methodology is achieved.

The thoughtful and careful revision of the intervention was done based on the findings obtained in the first PHASE and the following are among the adjustments that were made and implemented in the second PHASE:

(a) The searching of materials to make home-based instructional materials was only delegated to students without any assistance from their teachers. Teachers only shared the lesson objectives which guided the students to search for the materials;

(b) The researcher and the chemistry teachers agreed to put students in two levels of groups to make the process of making the instructional materials and participation in chemistry hands-on activities effective. The first grouping level was done using students at the same desk or two close tables. Students sitting on one desk made one small group same applies to those sitting on the alongside tables. The second level of grouping was done between students from two adjacent tables within a column. With this juncture, the groups simplified easy monitoring of the process, saved time that could be used for the facilitation of the whole class, and enhanced peer mentorships;

(c) It was decided that the class hours could be only for learning facilitated by the instructional materials already made outside the lesson sessions. It was done so to follow the normal routine of the lessons and school timetable.

In the second PHASE, the adjustments made after reaching a consensus between teachers and researcher were implemented and the students were very cooperative and ensured that they had appropriate instructional materials which corresponded to the lesson content. Also, students demonstrated a significant increase in the acquisition of learning skills like curiosity and problem-solving skills (the results for these indicators are published in other manuscripts including (https://doi.org/10.29333/ejmste/10856), which also indicates the success of the implementation of this methodological approach.

Besides, all the adjustments required were made and implementation of the refined intervention continued for approximately three weeks in the second PHASE to ensure that students were getting used to the design and attainment of the saturation of data. Therefore, the second PHASE of the intervention makes the strengthening and the refinement parts of the designed HIM prototypes.

Considering the fact that this research project was design-based and a successful DBR requires many circles of alteration, time was one of the limiting factors of this study. In addition, maximization of the study sample should be considered for the replicability of the study findings (Bakker & van Eerde, 2015; Carstensen & Bernhard, 2019), because DBR supports the generalization of the research findings.

However, constant monitoring of the work that was performed by students in their groups was paramount and deemed necessary in this endeavour to ensure enough information is obtained to justify the success of DBR in this research project. Also, triangulation of the information obtained from multiple sources of data (Migiro & Magangi, 2011), was taken into account to check for the accuracy of the information obtained in this research.

The methodological implication of this project includes:

(a) The fact that DBR requires researchers to capture in-depth information in the real world, this research methodology should be considered as a reliable methodology to give chance to researchers to share the experience obtained regarding the success and failures encountered in the research process. These experiences ought to inform the decision-making regarding the artefact, intervention, or theory which is the outcome of DBR;

(b) DBR is essential in decoding the messiness and complexity of the real-life learning environment where such projects are always employed;

(c) The research findings of this project have revealed that the Hands-on Instructional Model designed in this research has an impact on creating a generation of independent learners. These learners are familiar with their environment, capable of integration of knowledge obtained from the class to the experiences outside the class, and possess well-established basic learning skills like curiosity and problem-solving skills. These skills are greatly needed in the current twenty-first world of globalization.

Conclusion

From the findings, it is clear that, design-based research is a viable alternative to a research methodology for science researchers conducting their research in contexts of education that are still facing challenges in the learning process. Not only be addressed and stay in literature and artefacts but also practically applied to bridge the gap between theory and practice. For those researchers interested in learning how to combine the interests of robust design with research results that could be used by a larger audience. Design-based research provides promising options, which seem to be much more fruitful for the field of education as well as individual students and practitioners collaborating with researchers. Nonetheless, design-based research requires a careful plan from the identification of a problem to the application of design principles.

Generally, it can be noted from the findings that DBR is a flexible design that provides numerous benefits to researchers by preparing them for lifetime professional contributions. This is because DBR is focused on building artefacts, theory, models, and intervention building. The design theories, models, and interventions save to improve educational practices not only within the design population, rather in any real-world educational setting of a similar context.

In particular, with DBR, the design and innovation are integrally linked to a contextual framework. Then, the great strength of DBR may be its level of specificity and not its generalizability. In this matter, it is time for educational researchers to consider the use of this emerging research methodology in educational contexts.

However, given that design researchers develop theories, systems, models, and interventions based on educational practitioners' views, it is obvious that the practicability of design outcomes will be high. This is because most of the design research outcomes have not been so practical due to their contradiction with real word educational contexts. Therefore, the practicability of the design outcome will be due to the willingness of practitioners to apply theories of their practice.

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