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The Effect of Video-Based Pedagogy on Students' Spatial Ability in Solid Geometry

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Abstract: This study explored the effect of video-based pedagogy on students' spatial ability in solid geometry, in the Birim Central Municipality of Ghana. A mixed methods concurrent triangulation research design was employed. The same treatment and methodologies were used on two intact classes (n=43 and n=39 respectively) of the two study schools. Descriptive statistics was used to analyse the questionnaire data, whereas data reduction technique and content analysis were used to analyse the interview reports and written test scripts data. The two separate data sets produced similar results, with the qualitative results confirming the quantitative results. The findings reveal that video-based pedagogy significantly promotes students' 2D and 3D spatial ability, and fosters students-centered learning in solid geometry. The results also provide evidence and recommendations on the significance of video-based pedagogy in improving students' mathematical understanding at the Senior High School level.

Keywords: Video-Based Pedagogy, Solid Geometry, Spatial Ability, YouTube Videos

1. Introduction

Technology use in today's mathematics classroom is believed to be effective in teaching and learning, thereby having positive impact on students' success and attitudes towards lessons. Teachers need to have knowledge in using Information and Communication Technology (ICT) to improve their teaching methods and approach is desired to promote effective learning as well as to meet the demand of the 21st century teaching skills (Ghavifekr & Rosdy, 2015). Hence, "effective teachers optimize the potential of technology to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics" (NCTM, 2011, p. 1).

There are several advantages from using the technology in the classroom. Technology helps pupils pay attention and comprehend mathematical concepts more clearly (Khouyibaba, 2010). Employing computers and technology in the classroom can aid both students' learning and teachers' delivery of the subject (Doan, 2012). What is more, ICT integration in mathematics education offers mathematics teachers with integrative teaching methods that motivate students' learning, support their independent learning and active participation in the discovery of mathematics concepts and topics that helps them have deeper understanding of the mathematical ideas (Baya'a & Daher, 2013).

Undoubtedly, even with the abundance of technologies available at schools, Agyei and Voogt (2011) affirmed that mathematics teachers in Ghana do not integrate technology in their teaching despite government efforts in the procurement of computers and establishment of computer laboratories in most Senior High Schools (SHSs). They argued that the use of the teacher-centred approach and lack of in-service and pre-service teachers' knowledge of ways to integrate technology in teaching as the main barriers. It is evident from the discussions that using technology in the mathematics classroom is not just an option anymore; but a necessity (Boggan, Harper and Bifuh-Ambe, 2009). Most importantly, today's students were born into a world with technology, so using technology-based pedagogy in mathematics should be natural for them. Therefore, to exclude these devices is to separate their classroom experiences from their real-life experiences.

Bray and Tangney (2017) asserted that the use of digital tools and technology-assisted mathematics education to enhance learning capacities are major study fields. The integration of technology into mathematics classes is growing (Tabach, 2011). While there is a growing body of literature on the efficacy of technology in various mathematical concepts, there is relative scarcity of research specifically focusing on use of videos on its effectiveness on solid geometry. This research aims to address this gap and shed light on the potential benefits of video-based pedagogy in the context of solid geometry.

This study, therefore, examined the effect of using videos as pedagogical and cognitive tools on students' spatial ability of solid geometry. The choice to focus on this topic among other topics in mathematics was informed by literature. Studies and reports have shown that students have difficulties and develop misconceptions when learning this aspect of mathematics. The following are the mostly reported students' difficulties in solid geometry: (a) inability to imagine and interpret drawn objects correctly, (b) confusion when visualizing and shifting from 2-dimensional to 3-dimensional views and vice versa (Patkin, 2015; Denenberg, 2011; Maida, 2005; Owens & Outhred, 2006; Özerem, 2012; WASSCE Core Mathematics Chief Examiners Reports, 2014).

2. Literature Review

2.1 Students' Difficulties and Misconceptions in Learning Solid Geometry

The literature points to the fact that students have difficulties and misconceptions when it comes to learning solid geometry. The discussions that follow highlight some of these difficulties and misconceptions. Patkin (2015) reported that pupils at elementary and even junior high school, when they see a ball in reality, it will look like a circle in a drawing since it is hard to describe 3D figures in a drawing which has a 2D figure. Another example is that a student may be given a cube but will call it a square which demonstrates that the student does not understand the difference between 2D and 3D objects (Denenberg, 2011). Maida (2005) reported that through teaching pre-service teachers, observation was made that they had difficulty making connections between a flat cut-out and its respective folded-up solid. Hence, Maida recognized the need for strengthening skills of visualizing 3D solids from various 2D nets.

Owens and Outhred (2006) also observed that perpendicularity and parallelism have an impact on making and interpreting drawings and on concept formation. However, when solving problems, some students thought all intersecting lines were at right angles or did not recognise them in rectangles and even better students did not recognise right angles without horizontal and vertical sides (Owens & Outhred, p. 94).

Such similar problems can be identified in the Ghanaian SHS context, which are found in the national examination explained in the West African Senior School Certificate Examination (WASSCE) Chief Examiners Reports on Core Mathematics. For instance, in 2015 candidates were given the question: A water reservoir in the form of a cone mounted on a hemisphere is built such that the plane face of the hemisphere fits exactly to the base of the cone and the height of the cone is 6 times the radius of its base. (a) Illustrate this information in a diagram; (b) If the volume of the reservoir is $333\frac{1}{3}\pi m^3$, calculate, correct to the nearest whole number, the: (i) volume of the hemisphere; (ii) total surface area of the reservoir. [Take $\pi = \frac{22}{7}$]. It was reported that, the performance of those who attempted the question was poor. Majority of the candidates were not able to represent the given information in a correct diagram, which was necessary to guide them to answer the questions.

From the preceding discussions, it appears to suggest that one underlying premise contributing to students' difficulty in developing their understanding and interest in learning in solid geometry concepts is the manner the topic is structured and presented. As a result, this study focused on the effect of teaching solid geometry with video-based pedagogy on students' spatial ability of solid geometry; through hands-on activities, small group and whole class discussions.

2.2 Video-Based Pedagogy

Video is defined as the selection and sequence of messages in an audio-visual context (Canning-Wilson, 2000). The audio is the sound received as learning messages via the sense of hearing, while the visual is moving images that can be seen by visualization. According to Duffy (2008), "Video can be a powerful educational and motivational tool Effective instructional video is not television-to-student instruction but rather teacher-to-student instruction, with video as a vehicle for discovery" (p. 124).

Berk (2009) on *Multimedia Teaching with Video Clips* identified 20 potential outcomes on the learning value of videos in the classroom, some of which are: grab students' attention; focus students' concentration; generate interest in class; create a sense of anticipation; energize or relax students for learning exercise; draw on students' imagination; improve attitudes toward content and learning (p. 2).

Research is increasingly challenging the pervasive belief that television and video viewing is a passive activity and viewers are only affected trivially with what they are watching and with time television and videos will hinder or have precedence over academic achievement (Cruse, 2007). However, Cruse (2007) supports the theory that viewing is instead an active process, one which can be 'an on-going and highly interconnected process of monitoring and comprehending' and 'a complex, cognitive activity that develops and matures with the child's development to promote learning'. More so, as with other instructional technological tools, the advantage of using video depends on the way it is implemented in the actual practice. Effective integration of video into teaching requires preparation before, during and after viewing (Shrum & Glisan, 2005). So, in this study, to further increase students' active involvement in the lessons, for every lesson they worked in small groups of 4 to 5 members, and they were assigned with activity sheet to answer questions, discussed scenes and engaged in hands-on activities while learning solid geometry by video-based pedagogy.

The video-based pedagogical medium consisted of YouTube videos. Duffy (2008) defined YouTube as "a popular video sharing website where users can upload, view, and share video clips. YouTube is increasingly being used by educators as a pedagogic resource…" (p. 124). The communication aspect of the YouTube videos is significant as it allows for the teachers and students to interact through discussion and activities (Johnson, 2013). YouTube as an online website is very common for all because of its accessible and free videos (Alwehaibi, 2015). YouTube videos cater to various learning styles, since they have a sense of attraction such as graphics, sounds, and colors (Vural, 2013).

Within the context of the problem under study, particularly Ghana, video-based pedagogy was preferred due to the following reasons. Agyei & Voogt (2011) pointed out that due to the complexity of problems most mathematics classrooms in Ghana face concerning ICT infrastructure and lack of application software, more generalised application that offers a technology readily available and user friendly among mathematics classroom to support students' higher-order thinking in mathematics is necessary (p. 436). Thus, the YouTube videos are readily available to freely download, and safe or watch online during lessons.

Again, teachers can easily deliver lessons with video-based pedagogy even without professional training in technological pedagogy. According to Fabos (2001), one of the most significant factors in the success or failure of an educational technology is the quality of the content, rather than the technology itself. Therefore, to maximise the effectiveness of the YouTube videos incorporated in lessons, audio-visually rich educational videos were carefully selected and subsequently downloaded. This was achieved by previewing and reviewing several videos on YouTube on particular solid geometry concepts.

2.3 Spatial Ability

Spatial ability has an important role in understanding geometry (Güven & Kosa, 2008; Hartatiana, Darhim & Nurlaelah, 2017a; Miatun, 2018). Students with high spatial skills can easily understand geometric shapes and the connections between the shapes (Baratti, Potrich & Sovrano, 2020; Yani & Rosma, 2020). Sjölinder (1998) defined spatial ability as the cognitive functions that enable people to deal effectively with spatial relations, visual spatial tasks and orientation of objects in space. Spatial ability also refers to the ability of an individual to perceive the visual world accurately and infer about the relationships between various geometric entities (Taylor & Tenbrink, 2013). According to Guven and Kosa (2008), spatial ability concerns one's ability to perceive, store, recall and create mental picture of shape and space.

Spatial ability is often grouped into spatial visualization and spatial orientation (Cakmak, Isiksal & Koc, 2014; Pak, Rogers & Fisk, 2006). Spatial visualization is the ability to manipulate an object in an imaginary 3D space and create a representation of the object from a new viewpoint (Strong & Smith, 2001), while spatial orientation is the ability to imagine how a given object or set of objects would appear from a spatial perspective different from that in which the objects are shown (Lohman, 1979). In another vein, Strong and Smith (2001) explained that, "spatial orientation requires only mental manipulation of a configuration in two-dimensional space while spatial visualization requires serial operations such as rotation in three-dimensional space or unfolding of flat patterns" (p. 2).

Given this obvious role of spatial ability in mathematics education, researchers have attempted to find ways to improve students' spatial ability. Studies have shown that students' spatial ability can be improved through training (Eisenberg, 1999; Onyancha, Towle and Kinsey, 2007; Robihaux, 2003). Furthermore, Piburn *et al.,* (2002) stated that spatial ability can be taught and practiced with classification, pattern detection, ordering, rotation and mental manipulation of three-dimensional objects can improve spatial ability. The use of technological tools is important for improving student's spatial ability in geometry instructions (Leong & Lim-Teo, 2002; Piburn *et al.,* 2002). This study is thus useful in its potential contribution to realise the effects of video-based pedagogy for improving students' spatial ability in solid geometry.

3. Methodology

3.1 Research Approach and Questions

The design used for the study was the mixed methods concurrent triangulation. The intent for using this design was to collect and analyse the quantitative and qualitative data separately on the research problem, compare and corroborate the quantitative results with the qualitative findings (Creswell & Clark, 2007). The study was carried out in the context of two different SHSs in Ghana. Two intact classes from the two schools were used. This was to ensure that students who consented to take part in the study benefited from the lessons, than randomly selecting some students from the class while leaving others. It further ensured that participants with similar characteristics were selected. More so, the use of intact groups does not disrupt the existing research setting, but keeps the participants in their natural settings (Dimitrov & Rumrill, 2003). Another approach followed in this study was conducting the same study in the two intact classes by employing the same video-based pedagogy, research methods and analysis. According to Fraenkel, Wallen and Hyun (2012), repeating a study with a number of similar samples is to decrease the likelihood that the results obtained were simply a one-time occurrence. The study was guided by the research question: *What is the effect of video-based pedagogy on students' spatial ability of solid geometry?*

3.2 Participants

Participants for the study comprised SHS 3 (final year) students in the Birim Central municipality of Ghana. Two schools (M & N *pseudonyms*) were randomly selected from schools with computer labs to facilitate the enactment of the technology-based lessons. Afterwards, one intact class each was randomly selected from the two schools with a minimum of 30 students as recommended by Fraenkel, Wallen and Hyun (2012) for experimental studies. Participants from School M class consisted of 43 students (32 males and 11 females) with average age of 17 years while School N class had 39 participants (21 males and 18 females) with average age of 18 years. The video-based pedagogy was used in both classes. In other words, the intervention was carried out in both classes. Final year students were considered ideal for the study due to the following reasons. They were expected to have learned the following SHS 1 and 2 topics, which are pre-requisite topics for effective teaching and learning of solid geometry and its mensuration concepts: *Change of Subject of an Equation*, *Plane Geometry I*, *Trigonometry I*, *Enlargement* (*Areas* and *Volumes of Similar Figures*) and *Mensuration I*. Again, the final year students were preparing for their final examination and therefore, it was reasonable and desirable that they need the knowledge on these areas in geometry most than the first and second year students.

3.3 Instruments

3.3.1. Questionnaire

Primary data collection was given priority in this research as there was limited published research on the subject under study. The questionnaire was used to collect quantitative data on students' self-assessment of their thoughts and experiences after learning solid geometry through video-based pedagogy. The instrument was divided into two sections; A and B. Section A elicited student's personal biographic data on age and gender. Section B consist of three statements in line with the research question, based on a 4-point Likert scale response format (*Strongly Agree=4, Agree=3, Disagree=2 and Strongly Disagree=1*). The scores were interpreted as: 4, the highest possible score indicating a very strong positive response, with 1 being the lowest possible score indicating a very strong negative response. All statements in the questionnaire were positively worded. In order to get the respondents to voice an opinion, no neutral point was included. The items were adapted from Agyei (2012; p. 237) and Lestari and Hernawati (2014; p. 662). The adaptations involved changing spread sheet to videos and ICT-based media to video-based instruction. Means and standard deviations were used to analyse the data and used in answering the research questions. The mean score interpretation for a four-point Likert Scale by Talib (1996) was then used to analyse and interpret each item in the questionnaire. The mean score of 3.01 – 4.00 are at a high level, 2.01 – 3.00 are moderate level, while mean scores of 1.00 – 2.00 are at the low level.

3.3.2. Interview

To facilitate the data triangulation during the analyses, the questions contained in the interview guide were aligned with those in the questionnaire. That is, the questions were drawn from the questionnaire instrument statements and students' classroom experiences. Five of the students from each school who took part in all the lessons on solid geometry were randomly selected and interviewed. This was done after collecting the questionnaire data. The interview data was meant to obtain rich data and provide in-depth elaborations for data collected through the questionnaire, and also used as evidence of students' justification of their thought processes in validating the quantitative results. The interviews were recorded transcribed and coded using data reduction technique (Miles & Huberman, 1994). Scoring rubrics and content analysis (Bryman, 2012) were used to analyse interviewees oral and written response to the solid geometry task.

3.3.3. Video-Based Pedagogical Lessons

In the study, the lessons that were taught in each of the two classes covered the following: *Identification and Classification of Solid Shapes*; *Drawing Solid Shapes and their Net Surfaces*. The aspects and the lesson objectives were drawn and restructured from: (1) the teaching curriculum (MoE, 2010); (2) examination curriculum (WAEC, 2014 – 2020); (3) WAEC chief examiners comments on candidates' weaknesses and mistakes on solid geometry question (2014) and (4) literature reports on students' difficulties and misconceptions when learning solid geometry. The original aspects under solid geometry as contained in the literature were restructured to suit the video-based pedagogy lessons. The lesson objectives were tailored to the Bloom's Taxonomy (Krathwohl, 2002); so that students thinking progressed from the lowest to the highest levels.

The lesson delivery part of the study lasted for two weeks with the implementation of two lessons (80 minutes per lesson) a week in each class. The student's activity sheet was also incorporated in the lessons. The activities sheets were intended to serve the following purposes during lessons: to sequence lesson activities, give direction to students to watch videos and undertake small group hands-on activities, prompt interactive discussion sessions, and practice exercises. So, the information on each activity sheet was aligned and tailored to the lesson plan and that of the PowerPoint slides projected through LCD projector during lessons. Thus, the video-based approach was student-centred. At the end of each lesson, the students present were assessed on a written test and given homework to evaluate their progress. The same researcher facilitated the lessons in both intact classes, while the other researcher acted as an advisor. After all the lessons, the questionnaire data was administered, and then followed by the interview sessions.

4. Results

As mentioned previously, the study investigated the effect of video-based pedagogy on students' spatial ability of solid geometry. After students had learned solid geometry concepts via video-based pedagogy, the Likert-scale questionnaire was administered, and the data gathered was analysed. Afterwards, the interviews were conducted, and interviewees' reports and work scripts were analysed. The qualitative results were used to validate the quantitative results.

4.1 Quantitative Data Results

The results in Table 1 compare the descriptive statistics of school M and N students' self-assessment of their spatial ability of solid geometry.

Table 1. School M & N Students' Self-Assessment of their Spatial Ability of Solid Geometry

Spatial Ability of Solid Shapes	School M (N=43)		School N (N=39)	
	M	*SD*	*M*	*SD*
The video demonstrations and simulations helped me gain enough understanding of the concepts in solid geometry	3.84	0.374	3.54	0.505
Sketching 2D and 3D forms shown in the videos helped me to visualise and understand the details of the solid figures	3.72	0.454	3.36	0.584
The videos helped me to visualize the concepts in solid geometry very well	3.70	0.465	3.51	0.506
Overall	**3.75**	**0.283**	**3.47**	**0.348**

Table 1 shows that the mean values for the statements under students' spatial ability of solid shapes in school M appear to be higher than that of students in school N. All the same, the mean values for both cases are within 3.01 – 4.00, which are at the high levels (Talib, 1996). The overall mean values of 3.75 of school M and 3.47 of school M are at the high level. The standard deviation values range from 0.354 to 0.465 for school M and 0.505 to 0.584 for school N indicating that the responses by the respondents are not very different from each other. These indicate that the respondents agreed that the instructional medium was effective in promoting their spatial ability of solid geometry.

4.2 Qualitative Data Results

On the solid geometry task: *A pile of sand is in the form of cone of base diameter 3 m and height 2 m. It is used to fill a rectangular jumping pit measuring 2.4 m by 1.9 m*. Interviewees were asked to: a) identify the properties of each solid shape in the given information and present this orally (for *oral understanding*) and b) draw and name each solid shape in the given information (for *written Understanding*).

Oral Understanding

Cone: a circular base, one vertex, a curved surface and one circular edge**.**

Cuboid: *6 faces, 12 edges, 8 vertices and a rectangular base*.

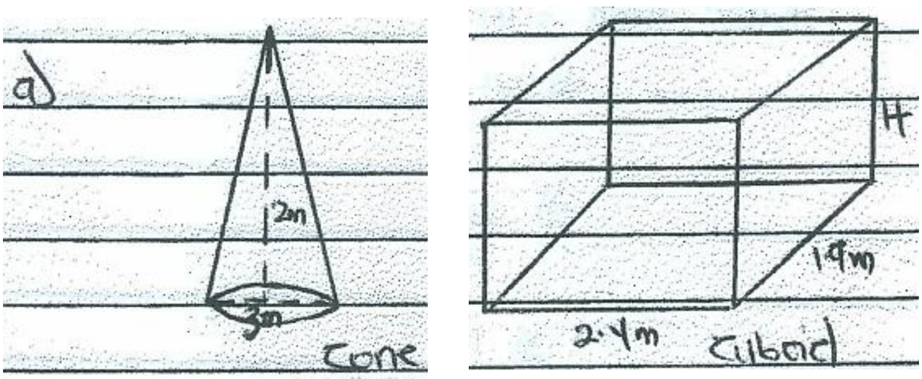

Figure 1. Excerpt and snapshot of student M05 answer to the question.

Many students from both classes were able to identify at least three properties of cone and cuboid, and clearly drew and labelled the two shapes, as required by the scoring rubrics. Figure 1 shows the work of one of the students in Class M (Student **M5**).

Figure 2 shows a snapshot of a Class N student's (Student N13) answer. Here too, the students were able to identify and mention properties of both the cone and cuboid, and also drew and labelled the two shapes correctly.

Oral Understanding

Cone*: one vertex, one curved surface and a circular base.*

Cuboid*: 8 vertices, 6 surfaces, 12 edges and cross sectional is a rectangle.*

Written Understanding

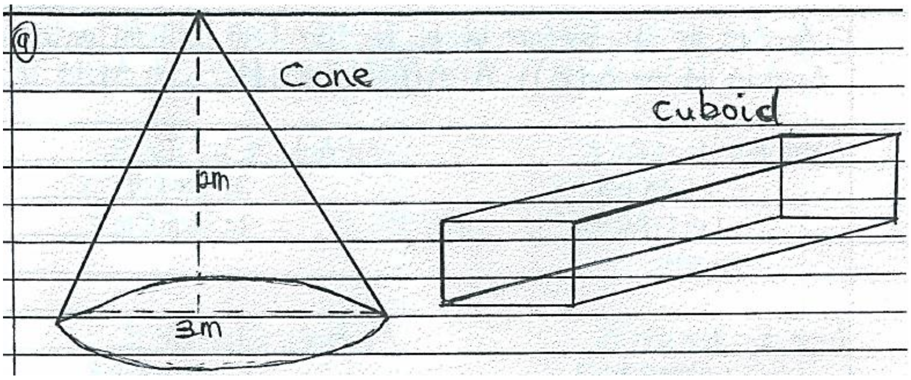

Figure 2. Excerpt and snapshot of student N13 answer to question

From the students' responses and work sheets, the use of the video-based pedagogy enhanced the students' spatial ability of solid shapes, more specifically, their spatial visualization and spatial orientation. Altogether, the qualitative data results from the interview and written task work sheets reports corroborated the findings from the quantitative data results. The results clearly suggest that the use of the video-based pedagogy contributed significantly to the students' spatial ability in solid geometry.

5. Discussion

It is interesting to note that both the quantitative and qualitative data analysis results from the two intact classes revealed that the students recognised that the video-based pedagogy bettered their spatial ability of solid shapes. The literature reviewed on students' difficulties and misconceptions when studying solid geometry pointed out that students have difficulty in visualizing and reasoning 3D shapes in 2D representations (Owens & Outhred, 2006; Patkin, 2015). However, the participants in this study were comfortable when visualizing and reasoning 3D shapes in 2D representations. This positive finding could be as a result of the videos simulations on solid shapes and nets of solid shapes employed in the lessons. The videos helped the students to vividly see the sectional views of the solid shapes when they were learning and solving questions. By this means, students' visual and spatial reasoning of 2D and 3D shapes improved considerably.

In the literature, it was evident that students find it difficult to describe and transcribe 3D figures based on observing it in computer or projector screen which is 2D (Patkin, 2015; Denenberg, 2011; Maida, 2005). In this study, it was observed that few of the students encountered this problem. In the second lesson, *Drawing Solid Shapes and Net Surfaces*, these students drew a circle to represent a sphere. Also, when drawing the net surfaces for the polyhedrons (i.e., cubes, cuboids, triangular prisms, rectangular pyramids, etc.) due to the oblique and isometric views of the objects both on paper and projector screen, the students drew rhombus and parallelogram to represent the square and rectangular faces respectively. However, upon showing them solid-shaped models and nets, these misconceptions were easily corrected to the extent that the students did not repeat them in subsequent lessons. In the case of the sphere, the students were asked to look at the spherical object (table tennis ball) and the sketch of the sphere in their diagrams sheet. In the other instances, they were asked to identify the respective solid-shaped models from the collections available. After examining the surfaces again, they understood that the surfaces were basically triangular, square and rectangular shapes as compared to how they initially thought. Through that, they were able to correct their mistakes.

The results of this study confirm the findings of previous studies. The study by Gün & Atasoy (2017) investigated the effects of an augmented reality application on students' spatial ability and academic achievement on the topic geometric objects and measuring volume. Their results indicated that there was a significant increase in the spatial ability of the students. The students commented that it was enjoyable and that it helped them to visualize abstract concepts in their minds. These studies also found out that, the teaching of mathematics using video-based instruction enhances pupils' academic performance in mathematics (Obielodan, *et al.,* 2017), and provides better learning opportunities and mediate gainful knowledge construction among students (Ramkalawon & Bholoa, 2014).

5.1 Implication for Research and Practice

The findings from this study raise some significant matters relating to the teaching and learning of mathematics. Towards the full realisation of integrating technology-based instruction in classrooms, particularly in Ghana; teachers are encouraged to design and enact innovative teaching and learning which foster students' engagement and practical learning of mathematical concepts. Stakeholders in education and school authorities should provide resources and motivational packages for teachers who integrate technology in their lessons to promote the use of technology-based instruction in schools.

6. Conclusion

The video-based pedagogy was effective, in that students developed mastery in 2D and 3D spatial ability of solid geometry. The students established the generalizations and connections that, polyhedrons have flat faces and straight edges, but non-polyhedrons have flat and curved faces or curved face only, with curved edges. Then, the net of a solid figure is 2D, and when the net is folded it becomes 3D. These positive developments were probably beyond what students would have gained through the use of the traditional teacher-centred approach, which is typically based on the use of paper, pen and calculator, in teaching and learning. It is therefore worth mentioning that the most beneficial aspects of using the video-based pedagogy were that it: developed students' spatial ability, established similarities and patterns in their study of solid geometry concepts. Therefore, as they have been able to grasp and demonstrate their knowledge on spatial ability of solid geometry concepts, it will definitely lay the foundation for them to better understand solid mensuration concepts when they are taught later.

Again, the video-based pedagogy provided diverse teaching experience for the students. The instant playback, rewind, forward and pause features of the videos allowed the students to learn at their own pace. The videos also added variation and clarity to classroom discourse. That is, the teacher's and students' voices were not dominating instructional discourse. Rather, we were always attentive to watch and listen whenever a video was screened. Thereafter, the students engaged in discussions, worked on tasks and shared ideas, which promoted students-centred learning. If video-based pedagogy is to be used as a cognitive tool to improve students' learning outcomes, then teachers need to take up the challenge and responsibility to optimize its potential, and increase students' proficiency in mathematics.

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Author Contribution Statement

Both authors equally contributed and approved the final manuscript.

Data availability

The Authors confirm that the data supporting the findings of this study are available within the article.

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