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Teaching bioengineering using a blended online teaching and learning strategy: a new pedagogy for adapting classrooms in developing countries

David O. Obada[1,5,6] · Raymond B. Bako[2,5] · Abdulkarim S. Ahmed[3,5] · Fatai O. Anafi[1,5] · Adrian O. Eberemu[4,5] · David Dodoo-Arhin[7] · Ayodeji N. Oyedeji[1,5,6] · Kazeem A. Salami[1,6] · Bassey O. Samuel[1] · Emmanuel T. Samuel[8] · Israel B. Obada[9]

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Abstract
Research and academia have been recently affected by the Coronavirus (COVID-19), and physical classrooms and laboratory experiments have been affected significantly due to the recent laboratory closures. This has led to innovative approaches to curb this problem. To address these difficulties in teaching bioengineering related courses that is of significant interest to students of the Faculty of Engineering in Ahmadu Bello University, Zaria, Nigeria, and of course, useful for engineering-based higher education institutions (HEI), a transitional pedagogy: Communicate, Active, Collaborate, Problem-based Solving, Learning and Assessment (CACPLA), which encompasses blended learning, was developed as a new teaching and learning strategy. In this study, we show that this new strategy can initiate a steady transition from physical classrooms to full online instruction for some subjects in engineering. This method has been trialled as an exercise for a module as part of an envisioned biomedical engineering degree programme which can be integrated with local industries and research institutions in sub-Saharan Africa. The teaching materials and environment were carefully designed and 253 students of third and final year classes participated as the experimental group. Also, the effect of critical thinking, pre-lecture, and post lecture on the overall performance of the students was assessed. Two questionnaires were designed for data collection, (a) for technical questions, (b) for receptiveness. The result of a student survey suggests favourable reception of the teaching methodology, which aided their understanding of the general bioengineering concept as applied to the materials chemistry and mechanical measurements context. It was noticed that 80% of the students indicated that the blended learning method was sufficient in achieving the learning outcomes of the study. The method is envisioned as a useful and sustainable complement to tra-

Extended author information available on the last page of the article

ditional teaching pedagogies and workshops due to the convenience and relatively high accessibility to Zoom and Google Meet Apps which can be readily employed without incurring significant costs.

Keywords Pedagogy · Bioengineering · Collaborate · Teach · Learn · Higher Education · Blended learning · Engineering Education

1 Introduction

Biomedical engineering is the application of engineering principles and design for health care purposes (medicine and biology) (Khan et al., 2013). It advances medical processes by being the interface between medicine and engineering wherewith the problem-solving skills and design of engineering are employed. Being a recently emerging field, it is common for its interdisciplinary nature to evolve to become a field itself. Notable applications of biomedical engineering include biocompatible prostheses development, chemistry of reactions of biomaterials, mechanically competent scaffolds, medical equipment development, implants, diagnostic equipment, tissue growth, drugs, therapeutics, etc. Teaching this subject using online classrooms and virtual laboratories in the face of the recent COVID-19 challenges will suffice. It may not be possible that virtual classrooms and laboratories will replace physical experiments, however these two can work together.

Online classrooms embedding virtual laboratory has shown to be a fascinating opportunity to engage students with online teaching to avoid disrupting academic activities which has been evident due to the recent pandemic. By reason of complementing physical classroom teaching with hands-on laboratory experiments, many students can gain the needed experience valuable for employment in the academia and industry. To put into context, biomedical engineering with its intricacies in terms of laboratory experiments has been taught conventionally and this have been significantly affected by laboratory closures.

Virtual learning has enhanced learning, just as stakeholders in education and research have increasingly become interested in leveraging the medium to increase learning outcomes even during limitations like lack of facilities, shortage of resources, and inadequate equipment, especially in tertiary institutions (Pape, 2010; Castro et al., 2019). The increasing popularity of the online learning media has been attributed to its flexibility regarding its access irrespective of time and location. Ahmadu Bello University, Nigeria, in its effort to meet current challenges in delivering an effective teaching and learning environment is adopting online teaching tools as a complement to physical classrooms. Ahmadu Bello University (ABU) is a Federal Government owned University in Zaria, Kaduna State, Nigeria. The university was founded on 4th October 1962 as the university of Northern Nigeria. The university operates two campuses: Samaru (main) and Kongo in Zaria. Specifically, the Faculty of Engineering has ten Departments (10) with various programs. The university hosts the Africa Centre of Excellence on New Pedagogies in Engineering Education (ACENPEE). ACENPEE is a centre of excellence to fill the gap that exists in the training of engineering professionals where there is over reliance on traditional teaching methods which hardly produce well-skilled engineers. The centre is implementing CACPLA, which is a modern, engaging, student-centered pedagogy that can produce high quality engineers.

The transition to online teaching in ABU was suggested and championed by ACENPEE due to the projected continuous increase of cases during the "second wave" with online classes seeming a real possibility. The potential sudden shift to full online instruction is leading faculty members to adjust their teaching and assessment pedagogies. Students may also face, as have been seen, the challenge to rapidly adapt to the new situation. With these uncertainties, three pedagogical approaches are of interest: (a) synchronous, (b) asynchronous, and (c) blended learning strategies. To put into context, the synchronous strategy allows teachers and students to meet virtually using a video conferencing application for course delivery. Students can ask questions verbally or through chats. The asynchronous lecture system allows teachers to record the lecture videos and upload them in learning management systems like YouTube so that students can assess at their convenience. The synchronous and asynchronous pedagogies lead to the blended online learning strategy. This blended pedagogy seems to be the most practical as it leverages on the advantages of synchronous and asynchronous methods. It is also cost effective because it significantly promotes interactive learning at relatively low cost (Bergmann & Sams, 2012; Olakanmi, 2017; Chick et al., 2020; Danjou, 2020; Fogg & Maki, 2021; Tang et al., 2021). However, the challenges for transitioning to a blended online learning strategy can be viewed in five folds:

1. Engaging the students with the lecture content can be challenging as it is a different learning environment when students attend classes in person as compared with watching a lecture online.
2. Replacing the hands-on learning activities with an aspect of virtual laboratories can possibly impact on some learning outcomes.
3. Creating a sense of community within a classroom setting can be impacted as in-person interaction can be reduced, and some time will be needed to facilitate peer interactions within the course modules.
4. In traditional classrooms, students develop a sense of cohesiveness through working on their group projects. The blended online approach may need extra scaffolding to encourage students to work together.
5. Ensuring accessibility to all students can be challenging, and several students can face a variety of home and learning environments which may include limited accessibility to internet, care giving responsibilities and/or time restrictions.

As online classroom settings are not common in universities in Nigeria, the recent COVID-19 pandemic fastened the transition process to online instruction for some engineering subjects with the opportunity to conduct effective online teaching considering the inherent challenges. The online platforms at the Ahmadu Bello University such as the Open Course Ware, Kubbani, etc. are used to store information where students can access for their learning process. These does not incorporate a live process in which the students interact with the teachers. In this way, the Zoom, Google Classroom, Prodigy Math Game, Flipgrid, Edmodo, Canva, Microsoft Teams etc.

have consistently been proposed to be in the forefront of virtual interaction. Being a cloud-based service, Zoom, Microsoft Teams, Google Meet etc. offers the online medium for meetings and webinars, providing the capability for video conferencing and content sharing.

We reckon that it is worthwhile to adapt and assess the CACPLA pedagogy to conduct successful online teaching considering our peculiarities as shown in the work by Eberemu et al., (2022). We hypothesize that this will provide a better comprehension of how the CACPLA strategy will pan out per its effectiveness in enabling instructors/teachers to fit their skills to online instruction given the resources at hand and the technologies present in these times. Three factors of online teaching have been investigated in this study viz.: (i) Content delivery (ii) learning methods, and (iii) assessment.

This study therefore attempts to use the Zoom application to teach students of the 3rd and 5th year of mechanical, metallurgical and materials, and agricultural and bioresources engineering some biomedical engineering lessons. The lessons focused on the chemistry of reactions of biomaterials and the mechanical behaviour of biomaterials with emphasis on the hardness of hydroxyapatite scaffolds. The asynchronous part of the teaching, using the CACPLA approach was achieved using learning management systems (LMS), with pre-recorded videos on YouTube. The synchronous part of the teaching was conducted using the Zoom video conferencing platform. An assessment of the student's receptiveness, and effectiveness of the blended learning pedagogical approach was investigated using a designed questionnaire which produced a quantitative and qualitative data for a probe into the success or otherwise of the teaching and learning sessions.

1.1 Theoretical Framework

It is important to note that students learn differently, nonetheless, there is no single unblended instructional design that may guarantee an optimal student engagement. Therefore, a learning paradigm that integrates multiple learning opportunities could be useful in stimulating the interest of learners. Stemming from these, we combine the features of the cooperative, hands-on, active, problem-based learning (CHAPL) pedagogy and the discover, learn, practice, collaborate and assess (DLPCA) pedagogy to enhance experiential learning in adapting classrooms in developing countries.

The cooperative, hands-on, active, problem-based learning (CHAPL) pedagogy encompasses the cooperative, active and problem-based learning (Golter et al., 2012). This pedagogy provides a better learning experience and has been quite effective in engaging students without compromising the course content, giving the students the opportunity to learn interaction skills that may be non-technical in nature. The discover, learn, practice, collaborate and assess (DLPCA) pedagogy, (Lapitan Jr et al., 2021) is a five-component blended learning method which combines asynchronous and synchronous teaching pedagogies.

The CHAPL approach can be successfully implemented in a traditional classroom with the help of desktop learning modules (DLMs) (Golter et al., 2006). These DLMs are used to deliver the core concepts and soft skills useful for a successful engineering career. Contextually, the DLMs with their operational manuals offer an easy way for students to receive training in the teaching of new paradigms, and in implementing the pedagogical techniques. The successes recorded in the use of CHAPL over the years can be ascribed to the continuous assessments and the refinement in the approach. The CHAPL approach afford students the opportunity to develop skills that aligns with the learning outcomes of the Accreditation Board for Engineering and Technology (ABET) criterion. The students gain domain knowledge and improve on their communication, teamwork, and problem-solving skills amongst others. Overall, the CHAPL approach details the roles of the instructor and teaching assistants as it relates to coaching several groups of students to narrow down the focus of their discussion and in assisting the groups to clarify misconceptions as they arise. In the DLPCA pedagogy, new information is delivered in a module-based approach where the concepts are linked and developed from modules already taught (Lapitan Jr et al., 2021). The lessons do not only centre around the technicalities of the topic at hand, but on real-world problems. Assessments follow the problem-sets, and this is to test the students' understanding and their skills in problem-solving. These strategies are enough to appraise the delivery of the pedagogy in terms of the concept inventory of the students. The pedagogical theories in the design of the DLPCA are learner-centred, however, the roles of the instructor and the technology adopted are also essential in the virtual classroom. Typically, in a learner centred approach, the instructors act as guides for instruction and provide the needed direction to the students (Owusu-Agyeman, et al, 2017). Therefore, students must take an active role in the decisions and personal learning process throughout the course, making the blending teaching strategy an effective approach.

For this study, the concept of CACPLA pedagogy hinged on the CHAPL and DLPCA pedagogies to develop a novel pedagogy that resonates with our academic settings. The asynchronous part of the teaching was planned through communicating lecture slide deck and posting pre-recorded lecture video(s) on YouTube to allow students learn at their convenience. The synchronous component of the teaching process was conducted using Zoom. The motivation for adopting a blended strategy was to enhance students' participation and advance their own learning process rather than being passive in a synchronous setting. The basis for this argument is the cognitive load theory which suggests that learners can be overwhelmed by a large chunk of new ideas that quickly make them resolve to surface learning (Seery & Donnelly, 2012; Darabi & Jin, 2013). The synchronous class time is based on further reinforcing the subject of the pre-class activities and includes interactions and discussion (Rau et al., 2017). This virtual classroom replaces the traditional physical classroom and the benefits of the blended online teaching has been reported by several studies (Lage et al., 2000; Kerr, 2015; Peterson 2016; Betihavas et al., 2016; Chiquito et al., 2020; Hodges et al., 2022; Wadams & Schick-Makaroff, 2022; Sharma et al., 2022; Liu et al., 2022).

From a pedagogical point of view, combining aspects of the CHAPL and DLPCA methods to coin CACPLA can be quite useful for sustainable e-learning in developing countries.

1.2 Related work

Liu et al., (2015) set out to develop a 3D virtual lab and this bridged the gap of student's involvement in the virtual learning process. In the study conducted by Giannaka et al., (2005), a virtual learning module was designed for teaching laboratory science practical where the student can directly participate in the learning process wherever they are. Online tools like Google hangouts have been studied in respect to its effectiveness as a teaching and learning tool. Kobayashi (2015) captured this when he undertook a cross cultural study on the effectiveness of an online virtual media for teaching and learning. Particularly, Google hangout was employed and results from qualitative data showed that even across cultures, the learning experience proved that Google hangout is a useful instructional tool.

Another important online tool which has proven to be effective in virtual learning is the Zoom application. Guzacheva (2020), studied the effectiveness of Zoom application in teaching English language and concluded that the positive learning outcomes was enhanced by the innovative technology embedded in the Zoom software. Also, Zoom presented an advantage such that those in remote areas could gain access to the same quality education, and this reduces the workload of the teacher. Chen et al., (2020) evaluated students' perceptions and preferences with learning online, particularly pre-recorded classes and other formats and the study showed that students showed a stronger preference to pre-recorded live classes. Surkhali et al. (2021) highlighted the accessibility and affordability of internet connection as a possible consideration for a switch to virtual learning with a considerable number of students living in rural communities. The study pointed out that the technical skills of teachers and students are a possible hindrance to the adoption of virtual learning. The authors suggested that limited access to internet in developing countries could pose a challenge.

Wardhono et al., (2020), assessed the perception of civil engineering students towards virtual learning during the COVID-19 era. It was observed that at the initial stage, the implementation was ineffective and posed a technical challenge. Other factors like time flexibility, social interaction, internet accessibility and cost were barriers to its effectiveness which agrees with the study of Surkhali et al. (2021). The study concluded with a recommendation that the institution implementing the virtual leaning method must also participate in making available the resources needed for it. Pusuluri (2020) assessed the perception of students in online learning during the COVID-19 lockdown and the study revealed that, with Zoom, students preferred online learning as it enhanced them to study at their own pace. Although the level of engagement was a problem, it was recommended that lessons taught through this medium should be more engaging.

Anwar et al., (2022), explored the application of blended learning on some projects in electronics engineering courses. The method the researchers adopted was project-based product design and development, and the results established the ability of the students to work by implementing project-based learning in producing products. Jamalpur et al., (2021), presented a comprehensive overview of online education and their impact on engineering students during COVID-19. It was highlighted that the blended teaching and learning strategy is now being adopted as a more robust approach in engineering education. It was suggested that teachers should interact more with the students when adopting this approach to learn the behaviour of the students and interests for different courses. Ramo et al., (2021) explored a blended teaching and learning strategy for a biomechanics course. The course was divided into three subject-specific sections: statics, dynamics, and mechanics of materials. The sections leveraged on the same instructional technologies and software tools; however, each section had a different ratio of synchronous to asynchronous components based on the instructors' preference and availability. The technologies and instruments utilized were compared vis-à-vis the facilitation of each section. The authors concluded that their methods align with many pedagogical approaches as outlined by Means & Neisler (2020). Simoes et al., (2021) in their work explored a virtual learning approach to courses in biological engineering during the COVID-19 pandemic. They reiterated that there were challenges posed by the virtual modality on pedagogical areas like course design, teaching methodologies, evaluations etc. However, despite the challenges, the performance of the students was enhanced. Higbee et al., (2021) created virtual spaces to build a community among students entering an undergraduate biomedical engineering program. They reckoned that to succeed in such broad and challenging programs, students may depend on interaction with their peers both in and out of the classroom. Therefore, it was imperative to identify virtual platforms with which communities can be built amongst incoming biomedical engineering students to develop evaluation methods and determine tools which might benefit students, post-pandemic. Rosario et al. (2022), in their work investigated the application of research-based teaching strategies in a biomedical engineering module focused on computer programming. The module consisted of a blend of lectures, active learning exercises, guided laboratories, and a final project. It was reported that after implementing this strategy, the students demonstrated a significant increase in conceptual knowledge, confidence with the material and a belief in the usefulness of the material from the beginning to the end of the module. Overall, the study presented an example of how multi research-based instructional strategies can be integrated into an undergraduate biomedical engineering course. Ahmed & Opoku (2022) used the theory of emergency management life cycle to examine the challenges faced by students and academics, and the coping mechanisms during the COVID period. The authors adopted a mixed method approach using a case study from a college of engineering at a higher education institution in the United Arab Emirates. The results obtained showed that technology supported learning tools are useful for enhancing students' learning experience and instructors with effective communication skills, competent use of technology, amongst others played a positive role in mitigating against the lack of preparedness in the transition from physical to blended teaching and learning approaches. The study also established that surmounting some of the challenges faced in facilitating blended teaching and learning can create new opportunities for the use of blended learning approaches to meet the needs of future online deliveries, post pandemic. Alkabaa (2022) analyzed and investigated the experiences and perceptions of using Blackboard as an online platform using a survey-based study developed and distributed amongst undergraduate students in an engineering college. The results were significant as it can help educational decision makers in enhancing the quality and sustainability of e-learning resources. Eberemu

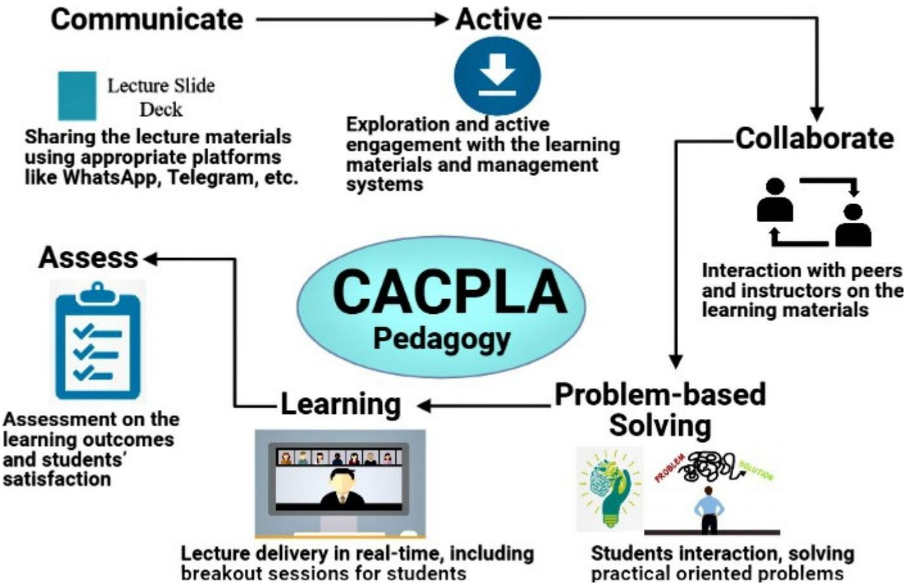

Fig. 1 Six components of the CACPLA pedagogy

et al., (2022) adopted a new pedagogy, CACPLA, to a typical geotechnical design of a foundation course to fourth year civil engineering students at the Ahmadu Bello University, Zaria, Nigeria, to experiment on the student's learning outcomes. It was concluded that using the CACPLA pedagogy can enhance the enthusiasm of students in geotechnical engineering education. Obada et al., (2021) showcased how science and engineering courses can be taught more effectively using the backward design approach. Five case studies of undergraduate science and engineering courses were outlined, and the backward design approach was utilized to put them into context. It was concluded that highlighting distinct learning outcomes, aligning evaluation methods and all aspects of the curriculum and instructional materials can enable experiential learning outcomes to be evaluated real-time in the classroom.

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1.3 A description of the new transitional pedagogy

The CACPLA teaching and learning strategy was developed for the blended learning technique with the goal of integrating the instructors, students, and readily available technologies like Zoom. Figure1 shows the six (6) components of the approach with a brief explanation of each component. Learning materials were in the first instance *communicated* to the students on the subject to be taught via their WhatsApp platforms. Next, the students actively interacted with the materials by exploring and downloading all materials such as the slide deck, YouTube videos, etc. The students *collaborate*d by discussing the shared materials amongst each other. An intriguing aspect of the collaborate component of the pedagogical approach is centred around the roles of the instructor and the teaching assistants who act as coaches to assist the collaborating group of students in narrowing the discussion focus and guiding the groups should misconceptions be encountered. On occasion, the instructor and teaching assistants can help the groups in resolving conflicts that may arise. The central piece to this approach is the "Jigsaw" group. This approach ensures that students are first split into home groups and the team members are assigned concepts that are relevant to the broad field of the module under consideration. Next, new "Jigsaw" groups are formed to comprise students from each home group who can share the responsibility for a concept with access to small hands-on modules which allow the concepts to be explored. The groups are expected to take time as allotted by the instructor to study concepts in the module and formulate a learning package to take back to their home groups. Essentially, all the formulated learning packages are reviewed and edited by the instructor to ensure they align with learning outcomes. The *problem-based* component involved students solving open-ended questions/problems that are of real-life applications as highlighted in the learning materials. The *learning* component consisted of the synchronous sessions where the students were taken through the lecture materials by the lecturer/instructor with an enhancement in teacher-student engagement. The students are then *assess*ed based on the learning process and the learning outcomes.

1.4 Design of the teaching materials and environment

The design of the asynchronous and synchronous aspects was designed by linking the theoretical concepts with the practical aspects of the subject as it relates to mechanical measurements of biomaterials. The scientific background of the students concerned were agricultural and bioresources engineering, mechanical, and metallurgical and materials engineering. Biomedical engineering, which involves somewhat different knowledge (physics: chemistry, heat and mass transfer, mechanical measurements etc.), is of course, a fit to fundamental science for the students. It was noticed that only a few had engaged with a technology platform and they needed to update their basic abilities. Many of the students involved had a computer or an android phone and reliable internet connection, with some cases of instability in internet connection which may be characterized by low speed.

1.5 The remote labs environment

The remote work environment used was a learning management system (LMS), YouTube, which gave the students access to the pre-recorded video of the hardness measurement test protocol for hydroxyapatite derived bio-scaffolds. The technology platform managers carefully checked the videos and the quality of audio since it was key for effective stand -alone learning, and several suggestions were made to enhance the quality when needed.

2 Methodology

2.1 Recorded lecture videos

Recorded lecture videos and teaching slides were shared with students before the synchronous sessions. The lecture videos and teaching slides were made simple, readable, visually appealing, comprehensible, brief, and easily accessible for students. The lecture notes were made as slide deck in power point and the video was recorded with a phone and saved as a MP4 file. Sound quality adjustments included the addition of introductory and end music animations using Adobe Premiere Pro video editor software. The lecture videos were then uploaded on YouTube for accessibility and the link was shared with the students through their WhatsApp platforms.

2.2 Participants

The students of third and final year classes participated as the experimental group (N=253). For the pre-test, 168, 60 and 25 students participated from mechanical, metallurgical and materials and agricultural and bioresources engineering departments, respectively. While for the post-test, 123, 49, and 13 students participated from mechanical, metallurgical and materials and agricultural and bioresources engineering departments, respectively. During the critical thinking session, 147, 52 and 28 students participated from mechanical, metallurgical and materials and agricultural and bioresources engineering departments, respectively. The large number of students from mechanical engineering department was not unexpected, as students are admitted more to study mechanical engineering based on the choices made by the students during the admission process.

2.3 Data Collection

The questionnaires were designed with the aim to evaluate the effectiveness of the CACPLA pedagogy and collate the opinion of the students on teaching and learning bioengineering. Two questionnaires were designed, (a) for technical questions, (b) for receptiveness.

The case study presented involved the experimental group of learners and contains several steps:

Activity 1: Training the students on the use of the Zoom software.

Activity 2: Knowledge pre-test (asynchronous).

Activity 3: Teaching online (synchronous).

Activity 4: Critical thinking session and knowledge post-test (asynchronous).

Activity 5: Learner Satisfaction Questionnaire (LSQ).

A breakdown of the activities is as follows:

Activity 1: Zoom lecture presentation.

Lecture slides on how to download, install, and use the zoom application was given to the students to bring them up to speed with the knowledge of the video conferencing platform.

Activity 2: Knowledge pre-test.

The subject of biomaterials was introduced to the students by sharing/communicating the learning materials. It was assumed to be a new field which the students were yet to explore. The study material contained a general introduction about hydroxyapatite, a notable calcium phosphate and its biomedical applications. The students were introduced to the concept of hardness and hardness test methods to accurately conduct mechanical measurements.

Next, the knowledge pre-test was administered to the students to assess their level of understanding of the subject matter. The pre-test questions were drawn out of the introduction and the general knowledge of the subject matter. The scores of the students in respect to the questions asked were used to benchmark and ascertain the level of their knowledge in the subject. The questions asked were multiple choice single response type of questions. The set time for responses to be turned in was 30min.

Activity 3: Teaching and video.

After the administration of the pre-test, a concise lecture (40min) on the content of shared materials was delivered to the students. This was delivered using the Zoom platform by the instructor with the attendance of the students collated online. A slide deck in power point was used to structure the teaching. Also, a five-minute video presentation on the laboratory process (pre-recorded video) of carrying out the hardness test was played so that the students can refresh their practical knowledge/overview of the hardness test concept. Our greatest motivation for preparing our own video was to gain the advantage of being more personal to the students. Some studies have reported better student learning experience and very strong preference for video/multimedia prepared by their instructors. Studies have also shown that students reported a higher level of engagement and expressed strong preference for multimedia created by their own instructor in an online course (Briggs, 2005; Xu & Jaggars, 2014).

Activity 4: Critical thinking and knowledge post-test.

A critical thinking session and knowledge post-test was carried out after the synchronous session to assess the students grasp of the subject matter. The questions were based on the content of the lecture delivered. The critical session was based on 10 questions using the google form with multiple choice-multiple response type of questions per session, while the post test was based on 10 questions with multiple choice-single response type of questions per session. The set time for responses to be turned in was 30min.

Activity 5: Learner satisfaction questionnaire.

A learner satisfaction questionnaire was administered to the students to assess their satisfaction with the learning process. Specific questions regarding their perception of the learning process were asked. The LSQ was made using the google form and composed mainly of Likert scale questions. The last section of the satisfaction questionnaire also invited students' feedback or remarks through open-ended questions. The google form link containing the questionnaire was sent to the students through their WhatsApp groups. The set date for responses to be turned in was a period of one week.

3 Results

The results obtained from the pre-lecture assessment, post-lecture assessment, critical thinking assessment and learner's satisfaction survey is presented in this section.

3.1 Comparison of pre-lecture and post-lecture assessments

First, the results on the comparison of the pre-lecture and post-lecture assessments are presented. The pre-lecture assessment was administered to the students 30min before the scheduled synchronous session (Zoom lecture session), with the aim of assessing the students' knowledge on the subject matter based on the learning materials previously given to them. This also measured the effectiveness of the first asynchronous process. The post-lecture assessment, however, was given to the students immediately after the synchronous session. This synchronous session involved a further buttress of the subject matter and interaction between the students and the lecturer/instructor in the form of a question-and-answer session. The post lecture assessment was facilitated via a prepared google form whose questions covered the course lecture that was taught during the synchronous teaching session, and the score of each student was recorded. Efforts were made to limit the entry of each student to 1, and a form time limiter add-on was used to time the accessibility to the form to limit collaboration between the students during these assessments. A summary of the comparison of these results is shown in Fig.2.

This result showed that a significant percentage of the students (91.86%) scored above 50% of the total score in the pre-lecture test. This is attributed to several factors such as the simplicity of the lecture materials which made the students find it easy to explore, the activeness of the students in exploring the lecture materials and

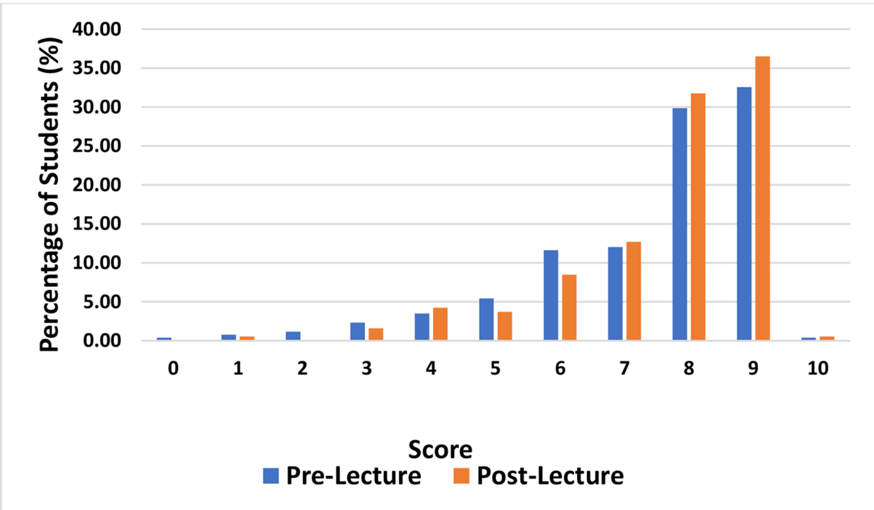

Fig. 2 Comparison of students score for post-lecture and pre-lecture assessments

the collaboration between the students regarding the lecture materials which may include having virtual group tutorials to cover unclear areas in the material, proving the effectiveness of the *collaborate* and *active* processes. Tucker (2012), Bergmann et al., (2013), and Nerantzi (2020) in previous studies have established that the importance of the collaborative aspect in the learning process cannot be overemphasized. Furthermore, the result showed that more students (93.65%) scored above 50% of the total score in the post-lecture test. The effectiveness of communicating the lecture materials and the students getting active and collaborating before the lecture is proved with the increase in the scores of the students after the synchronous session, as captured in the *learning* process of the CACPLA pedagogy. During the lecture session, the lecturer/instructor was able to explain in details certain areas in the subject matter that seemed vague to the students. The pre-lecture test also helped the lecturer/instructor in highlighting the areas which the students found difficult in comprehending, thereby giving an insight on where to lay teaching emphasis during the lecture. Similarly, the lecture process was characterized by some interactions between the students and the lecturer/instructor during the question-and-answer session. These factors amongst others as buttressed by Negovan et al., (2015) could be responsible for the increase in the percentage of students who scored above 50% in the post-lecture assessment.

Herein, based on the pre-test data, we can infer that the asynchronous part of the CACPLA pedagogy promoted the comprehension of the students as it allowed the students to be responsible for the progress ascribed to their learning. Nonetheless, relying on this method alone may be counterproductive as students will not be able to get instant feedback from the lecturers/instructors and vice-versa. It may also cause a feeling of disconnection from their lecturers making the students less motivated. Hence, the synchronous session which led to the post test, with students scoring slightly more, provided more effective dialogue between lecturer and students which is crucial to providing clarifications on the modules taught.

3.2 Critical thinking Assessment

Critical thinking can be described as an important outcome that should be one of the characteristics of higher education as it is a necessary tool for problem-solving and independent thinking. Critical thinking is further described as the ability to examine an issue by dissecting it and consciously evaluating the issue by providing evidence to support each evaluation. There are several ways of assessing the critical thinking ability of students, such as thinking through inquiry, critical thinking through writing, etc., We reckon that the environment the students learn and their capacities in comprehending concepts differ. This can be responsible for failure to keep pace with the synchronous learning session.

The critical thinking assessment employed in this study was the use of multi-answer question format. At the end of the post-lecture assessment, a critical thinking assessment was given to the students with a clear instruction *"Note: These are multiple-answer questions"*. The questions in this assessment were from the lecture materials, however, before a point is allotted to any question, the student was required to select all the correct options in the question set. This needed not only an in-depth

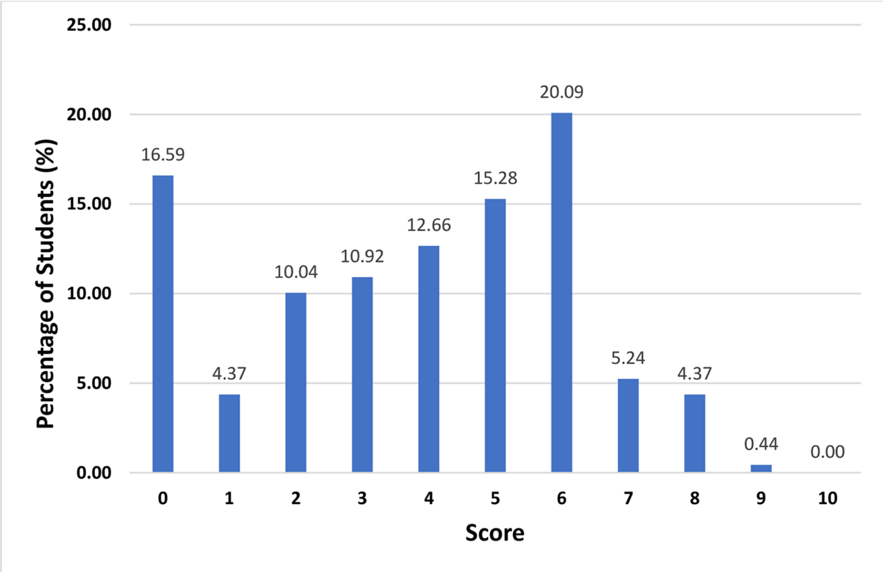

Fig. 3 Distribution of students score for the critical thinking assessment

understanding of the context of study but also a deep critical sense of reasoning. The process captured the *problem-based solving* as indicated in the CACPLA pedagogy. The result of the critical thinking assessment test is given in Fig.3.

The result showed a relatively low critical thinking skill among the students with only 45.41% of the students obtaining a score of more than 50%. One of the major factors responsible for this low critical thinking skill is the inability to keep pace with the synchronous session as highlighted earlier and sometimes failure to carefully read assessment instruction(s) before answering the questions. In as much as the synchronous sessions were used to further clarify difficult concepts as communicated, increased participation of students is to be allowed to ensure that they keep pace and can at the end of the session use what was learnt to move to the higher levels of the Blooms' taxonomy i.e., apply, analyse, and evaluate (Krathwohl, 2002).

We reckon that there are several ways of improving the critical thinking ability of students. Among them is the use of analogies, encouraging students to relate the subject matter to events in their surroundings, giving enough reflection time to the students during the teaching sessions, etc. Even though the result showed low students' grades, it proved that the questions were deep enough to command deep considerations and not just surface learning. Applying this problem-solving process during the lecture period will be more beneficial as it would stimulate the students reasoning and promote their concentration in the lecture. With regards to these, giving the students more time to solve the problems tend to improve the results of the problem-solving process.

We conducted a breakdown per department to assess the frequency of low scores and the reasons. This is as shown in Fig.4. The students from metallurgical and materials engineering department performed better in the critical thinking session and this

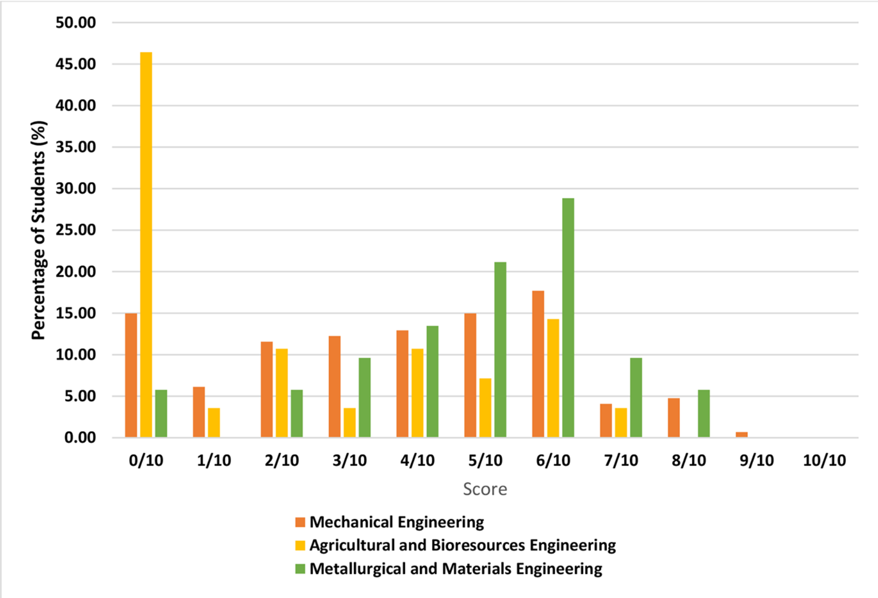

Fig. 4 Frequency per department for the scores in the critical thinking session

could be ascribed to their higher concept inventory as regards the courses they are taught, mostly on the behaviour of materials.

We have noticed that the uploaded video showed positive influence on the teaching and learning sessions before the synchronous setting. This is ascribed to the fact that at any time the students feel they need to understand the concept more, they revert to the video, grasp the knowledge by simply watching at their own pace and repeat watching when the concepts need to be better understood. With this, the flexibility and convenience through which the students have promoted their active learning can go a long way in reinforcing their comprehension of the subject. Flores & Savage (2007), and Smith (2014) showed previously that a students' performance is enhanced when pre-recorded videos and lecture materials are used during the teaching and learning process.

Nonetheless, one drawback with the pre-recorded video as a learning strategy is that the students are trusted to individually see the video clip to finish. If students don't watch these video clips fully to reinforce their learning, then complementing what have been learnt with the synchronous session would be difficult. The aftermath effect would be that the mastering of the learning outcomes intended at the beginning of the study will be lost. It is important, as a precautionary measure to address this drawback, prepare problem solving based self-assessment questions (SAQs) at the end of the lecture video to enhance the commitment of the students to complete watching the video. In this vein, students can be required to attempt and submit the SAQs as an exercise dedicated to applying the problem-solving skills in the video.

3.3 Learners' satisfaction

The learner's satisfaction survey was administered to the students at the end of all the assessments using a five-point Likert scale with responses from strongly agree to strongly disagree as shown in Fig.5. Students were asked in the first question of the survey to indicate their degree of agreement with the statement "The blended learning method used was sufficient to achieve the learning outcomes". 80% of the students indicated that the blended learning method was sufficient in achieving the learning outcomes of the study, in comparison with 17.21% who felt the blended learning method was not sufficient, and 2.79% of the students were undecided. Noticeable comments among the students indicated that with the blended learning method, students could ask more questions during the virtual lecture session including students who ordinarily would not have asked in the physical lecture class. Some selected comments are:

Comment 1: *"I think this method is an effective way for the learning process in tertiary institutions for all courses because it is highly interactive and everyone (all students and the lecturer) are involved compared to class teaching where some students feel shy of their classmates or lecturer in speaking up maybe for fear of mockery or some form of embarrassment just in case, he/she says something wrong."*

Comment 2: *"I strongly think this should be implemented in our way of learning because the understanding was on an individual pace and students who normally would have difficulty in asking questions due to shyness were able to."*

The second question on the survey asked the students to indicate their degree of agreement with the statement "I could easily answer the post-lecture questions after watching the video clip and participating in the lecture session". 84.65% of the students indicated that the video clip and lecture session helped in their ability to answer the post-lecture questions, compared with 9.77% who felt the video clip and lecture session had no impact on their post-lecture question-answering capability, and 5.58% were undecided. This result supports the data obtained earlier on the comparison of pre-lecture and post-lecture assessment in which there was a 1.79% increase in the number of students who got above 50% of the total score after the lecture session. Several comments from the students reinforce this, for example, some of the students' comments are highlighted:

Comment 1: *"The lecture was good enough, and I think the explanation is also fair in the pdf. I strongly recommend other courses to do the same. Thank you for the time you gave us."*

Comment 2: *"Today's lecture was far easier for me, and I enjoyed it especially the questioning session."*

The third question on the survey asked the students to indicate their degree of agreement with the statement "There was enough time to work on the learning materials at my own pace". 83.72% of the students agreed that using the CACPLA pedagogy, there was enough time for them to explore and work on the learning materials at their own pace. The time factor was also to enable the students to collaborate with regards to the lecture materials. However, 10.23% of the students felt they did not have enough time to work on the learning materials at their own pace. This can be because of negligence or constraints with power supply, insufficient data, etc.

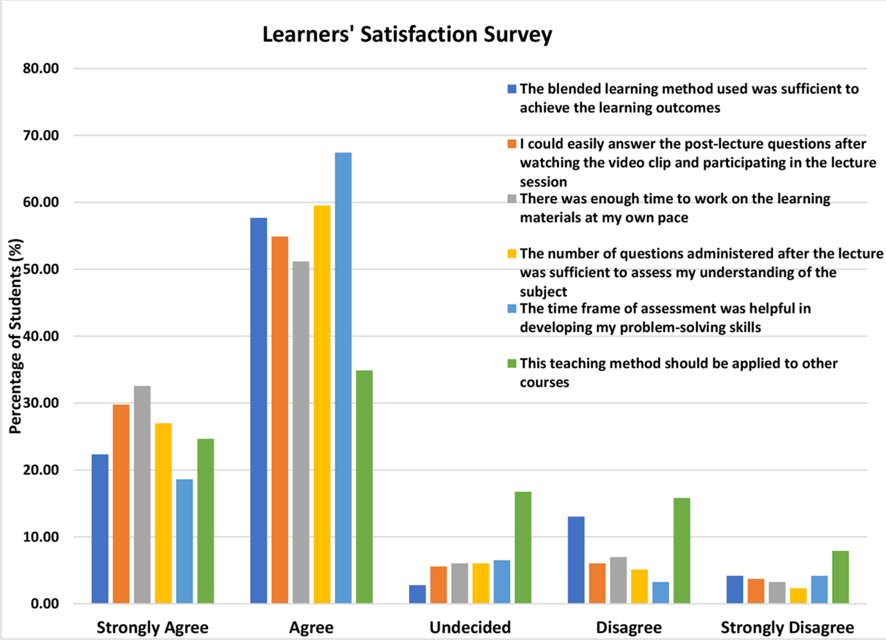

Fig. 5 Learners' satisfaction survey

Questions 4 and 5 on the learner's satisfaction survey asked the students to indicate their degree of agreement with the statement "The number of questions administered after the lecture was sufficient to assess my understanding of the subject" and "The time frame of assessment was helpful in developing my problem-solving skills", respectively. In each case, most of the students agreed that the questions administered were enough in assessing their understanding of the subject matter and that the time frame of the assessments helped in developing their problem-solving skills. Some of the comments of the students that reinforce these statements are:

Comment 1: *"Satisfactory and time-efficient"*.

Comment 2: *"I was able to sign in, but couldn't watch the video completely due to poor network service or too much congestion. Although, the tests were interesting because the questions were based on the slides given. Thank you!"*

The last question on the learner's satisfaction survey asked the students to indicate their level of agreement with the statement "This teaching method should be applied to other courses". The result showed that most of the students (59.53%) agreed to this statement of extending this teaching method to the rest of the courses, however, a sizable number of the students (23.72%) disagreed with this statement as shown in Fig.5, while 16.74% were undecided. This result with some of the comments of the students suggested some limitation of this teaching method. Some of these comments include:

Comment 1: *"My suggestion is that this method should not be applied to other courses because sometimes you would like to see your lecturer in your presence when* *you are asking him/her some questions because it enables you to understand him/her more."*

Comment 2: *"In my perspective, I think the online teaching method is awesome and should truly be applied to other courses if not for the issues of the unstable network, but I feel it is a welcome development".*

Comment 3: *"This method of teaching can be applied to many courses but I'm afraid there are a few limitations*:

1. *Network facilities should be upgraded to avoid disconnection and bad reception.*
2. *A framework should be developed to prevent students from cheating during the pre-lecture and post-lecture test."*

Comment 4: *"It's a nice teaching method but will be a bit tough for mathematical courses. The rate of understanding differs among individual. Some other factors that could affect these are*:

1. *Network availability, smartphones, and data subscription.*
2. *Computer & technical know-how."*

As observed from the comments of the students, some of the factors that are discouraging the extension of this teaching method to other courses from the students' perspective include unstable mobile network, cost of data subscription, inadequate technical know-how of some students, need for physical interaction with other students and lecturer/instructor, and cases of some students not having access to internet-enabled mobile devices.

Some of the observations from the learners' satisfaction survey reflects the views of Kirschner and co-workers (2006) that for optimum teaching and learning, the students should be given sufficient preparatory knowledge before expecting them to learn at their own pace. For CACPLA to be effective, very comprehensive, and guided instruction would have to precede the collaborate and problem-based solving learning components.

4 Discussion

The aim of this study was to explore the benefits of adopting the CACPLA pedagogy that combines the features of other proven pedagogies such as CHAPL and DCPLA. Among other things, we intended to establish that it is possible that an online teaching strategy can initiate a steady transition from physical classrooms to full online instruction for some subjects in engineering. The first component (communicate) of the CACPLA pedagogy which includes the necessary tasks and deliverables to the students further demonstrated the intention of the teaching and learning strategy to allow the students time to process the learning materials at their own pace. This process is important as it will allow students to carefully set their expectations with the new learning strategy and environment giving them an impression of a process that consists of several stages untill learning outcomes are assessed. The active, collaborate and problem-based solving components of the CACPLA pedagogy can increase the perception of learners on the intended tasks and motivation for learning because it promotes active engagement. The engagement is crucial to allow the learners comprehend the core engineering concepts and subsequently use them in creative ways. The balanced approach of CACPLA which combines the synchronous and asynchronous components to cater for the diverse personalities and peculiarities in an inclusive way maximizes the potentials for self and guided learning. The comparison of pre-lecture and post-lecture assessments establishes that having a sufficient and complementing blend of asynchronous and synchronous teaching strategies is essential for a robust experiential learning. The enhanced performance of the students per the post-lecture assessment suggests that the synchronous component enabled the students to express their feed-back, ask questions about the lecture materials, and clarify some misconceptions during the collaborate section of the CACPLA strategy. There is no gainsaying that the balanced blended approach embedded in the CACPLA strategy can assist the students establish proactive learning traits and unravel an immediate connectivity between the reality and the concepts taught (Novak & Cañas, 2007; Hunsu et al., 2015). This is quite useful in retaining the students' interest in learning the topics taught and would play a role in the subsequent retention in other engineering courses (Santiago and Hensel, 2021).

A possible reason for the high acceptance shown by the students in the learners' satisfaction survey is that they agree that the CACPLA pedagogy provides a cohesive strategy where the four components before the synchronous session allow the students know what to prepare before the meeting with the instructor/lecturer in real-time and are assured that some questions they have will be clarified during the synchronous session. This explains why despite the challenges about some aspects of the process in implementing CACPLA, most students still agreed that the new pedagogy has huge potentials to enhance the comprehension, integration, and application of core engineering concepts. Finally, our analysis of this exploratory study suggests that for CACPLA to be effective, there is a need for careful planning and systematic implementation.

4.1 The constraints faced in the learning process

In designing CACPLA, after studying different pedagogies, a consideration of the students' and instructors' technical and social conditions were considered. The different challenges were identified in the first instance and the constraints in the development of the CACPLA pedagogy are:

1) Due to technical constraints like the availability of the computers/laptops or gadgets, internet access, power interruptions, or personal limitations like family responsibilities, medical appointments, etc. students may have limited access.
2) The instructional materials must be made available for the students asynchronously and the difference in the speed of internet connection of the students must be considered.

3) Mechanical properties of biomedical materials involve practical aspects which must be properly taught to the students. The online delivery of the lecture may be a challenge in relating the practical aspect of the topic.
4) The internet maybe slow due to the large traffic of students learning online and workers who are working from home. Therefore, the platform adopted must be stable, and universally accessible for online synchronous class discussion. In respect to that, the platform must have the capability for call encryption for security, screen sharing, built-in video recording function and be added or synchronized to calendar.
5) In synchronous learning, poor internet facilities like slow or unstable connections may give the learners difficulty in joining the session rooms again therefore stressing them physically and psychologically.
6) Assessment methods must be re-structured to minimize academic dishonesty.
7) The management of the Ahmadu Bello University would have to be convinced about the continuous deployment of the CACPLA pedagogy.

5 Conclusion

Since online teaching with new approaches is now the order of the day for educators and learners, CACPLA was developed which matches with existing technology. It was important to evaluate the students' perception regarding the learning process and check the students' progress and modify aspects of the online teaching that is deficient. This article presented the CACPLA strategy which is a method that has paved the way for a transition from physical to virtual classrooms in adapting economies, post-pandemic. We noticed that the benefits of CACPLA outweighs the costs attributed to preparation for the learning sessions. The results of this study can be adapted in designing synchronous and/or asynchronous components of online classrooms. In addition, the CACPLA strategy can be applied in any future events which disrupts classes due to emergency situations that can lead to closure of schools or if a faculty member is not able to facilitate his/her lecture physically. The data presented in this study will allow preliminary adoption of the CACPLA pedagogy in online lecture delivery which hopefully will help in structuring a robust foundation for pedagogical decisions on online teaching to be made now and in the future.

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Declarations:
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Consent Statement: Not applicable.

Conflict of interest The authors declare no competing interests.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Authors and Affiliations

David O. Obada[1,5,6] · Raymond B. Bako[2,5] · Abdulkarim S. Ahmed[3,5] · Fatai O. Anafi[1,5] · Adrian O. Eberemu[4,5] · David Dodoo-Arhin[7] · Ayodeji N. Oyedeji[1,5,6] · Kazeem A. Salami[1,6] · Bassey O. Samuel[1] · Emmanuel T. Samuel[8] · Israel B. Obada[9]

✉ David O. Obada
doobada@abu.edu.ng

[1] Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

[2] Department of Educational Foundations and Curriculum, Ahmadu Bello University, Zaria, Nigeria

[3] Department of Chemical Engineering, Ahmadu Bello University, Zaria, Nigeria

[4] Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria

[5] Africa Centre of Excellence on New Pedagogies in Engineering Education, Ahmadu Bello University, Zaria, Nigeria

[6] Multifunctional Materials Laboratory, Shell Office Complex, Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

[7] Department of Materials Science and Engineering, University of Ghana, Legon, Ghana

[8] Department of Chemical Engineering, Kaduna Polytechnic, Kaduna, Nigeria

[9] Department of Sociology and Anthropology, Baze University, Abuja, Nigeria