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Students' Engagement in Mathematics with Virtual Resource: The Impact of Localization of PhET Interactive Simulation in Indigenous Nigerian Language

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

This study assessed the impact of a localized virtual learning tool; Physics Education Technology (PhET) interactive simulations on the achievements of students in Mathematics. The study adapted a questionnaire titled Student Engagement Measurement Scale (SEMS) in Mathematics. The SEMS has four latent constructs; cognitive, behavioral, agentic, and emotional engagements used to observe the impact of the localized virtual learning tool on students' achievements in Mathematics. A sample of three hundred and thirty three (333) pre-degree students within the targeted population participated in the study. Using exploratory factor analysis (EFA), the SEMS recorded 62.89% as the average variance extracted from the latent variables. Using regression analysis, agentic engagement showed a significant impact on students' achievement in Mathematics. This underscores the positive effect of efik/ibibio as part of the language of Instruction in Mathematics classroom. Students' emotional engagement with the localized virtual learning tool showed a significant positive relationship with their corresponding academic achievements in Mathematics. This underscores the fact that socio-cultural mathematical resources improve students' interest in Mathematics. Cognitive and behavioural engagements which measured some forms of mental alertness, manipulative skills, transfer of learning, and tasks-attention-responses in class, yielded positive significant impacts on students' academic achievements in Mathematics. Hence, diversification of instructional practices through the leverages offered by localized digital resources improved learning achievement in Mathematics.

Keywords: Engagements; mathematics; virtual learning resources; localization; PhET interactive simulation.

1 Background of the Study

1.1 Introduction

Technology-Enhanced Learning (TEL) is becoming a topical issue for the twenty first century learners in our Educational system. This is where technological tools can be used for a variety of purposes such as radically challenging and creating both a fearful and fascinating learning environment. On one hand, fearful conjectures regarding technology for mathematics suggested that people use subjective sense as they believed that technology creates chaos in learning of mathematics. They are of the opinion that students are not fully engaged in the learning process and do not take responsibility for their knowledge building because they are fully engaged with technologies that provide the possibility of accessing information immediately (Daniela, 2020). They posit that the use of a technological solution makes students lazy and feel redundant in the classroom. Smart learning devices are blamed for many of the problems we are facing and even in the near future. For example, technologies will take over all the jobs; technologies reduce the ability and desire to learn; the use of technologies reduces attention span; and so on. On the other hand, there are fascination situations where technology has been assumed to be the tools which will solve all possible problems; they will make the learning process interesting; students will become motivated; they will ensure rapid knowledge growth and will support the sustainable development and the well-being in the society. The latter perspective is in support of the future of mathematics teaching and learning, which is in line with the possibility of achieving the Sustainable Development Goal in 2030(Unicef, 2021). The aspect of inclusiveness, equitable and equal Education for all in the nearest future can be achieved globally through localization of virtual learning resources as a parameter for efficient remote learning environment.

In the Nigerian educational context, mathematics has been envisaged as a core subject in the curricula for both urban and rural secondary schools. The subject becomes an immediate antecedent for sustainable development and building of smarter human resources that can venture effectively in all facets of human adventures. It has been envisioned as the bedrock of Science Technology Engineering Art and Mathematics Education (STEAM) (Judijanto et al., 2024a,b) and as a requirement for an optimal learning environment. It is not new that technological tools has been integrated into the teaching and learning of Mathematics (Jorgensen et al., 2021), such as the use of dynamic geometry applications and other virtual manipulative tools. On the other hand, virtual and digital learning environment breeds digital divides to remote learning, and indirectly requires more teachers commitment in improving their Technological Pedagogical Content Knowledge (TPACK) for smooth explorations. Numerous challenges due to digital divides include the lacks of online learning resources and internet instability, and learning applications system that supports ethno-culturally related learning resources in our rural communities.

On a global scale, Language has been reported to provide a symbolic means to direct, control and channel thinking in a logical way as reported by Trends in International Mathematics and Science Studies (TIMSS, 2024) (National Center of Artificial Intelligence and Robotics, 2024). They highlights language as a factor that can undermine the performance of learners who speak different language at home from the language of instruction in the classroom. In the Nigeria context, the diversity of first language (L1) plurality is an added advantage for the under-privileged learners, but the exploration and integration of such opportunity is far-reaching when it comes to experiential, and flexible teaching and learning of Mathematics. Indigenous students are well equipped with home language or mother tongue before they come to the classroom, and it become advantageous to adopt a language integrated technique during instructional delivery. Thus, the adoption of L1 in relation to the language of instruction has been envisaged as a pathway to effective communication of the subject matter to the learners, while creating more adaptive learning experiences. The first language as an embodiment of enculturation preserves diversity and inclusivity through continuous usage, and incorporating it into instructional models becomes expedient. The use of L1 during instruction can reduce the threat of language extinction and promote cultural relevance, cultural transfer, shared group identity, sociocultural mindedness, sense of belonging, and lifelong learning.

1.2 Conceptual frameworks

1.2.1 Students' engagements in virtual learning resources

The post-COVID-19 experience drives teachers and educators to explore ways to supplement classroom instructional delivery through students' participation in virtual learning resources. Students' engagements connote their physical, manipulative and psychological involvements in the teaching and learning processes as they are taking responsibilities of knowledge creation in a virtual learning landscape (Maričić and Lavicza, 2024). According to Atkins and others in (Shernoff and Shernoff, 2013; Astin, 1984), engagement is multidimensional that consists of direct and indirect constructs of observable and non-observable four (4) components, namely; cognitive, behavioral, emotional and agentic(Reeve and Tseng, 2011) (see Fig. 1).

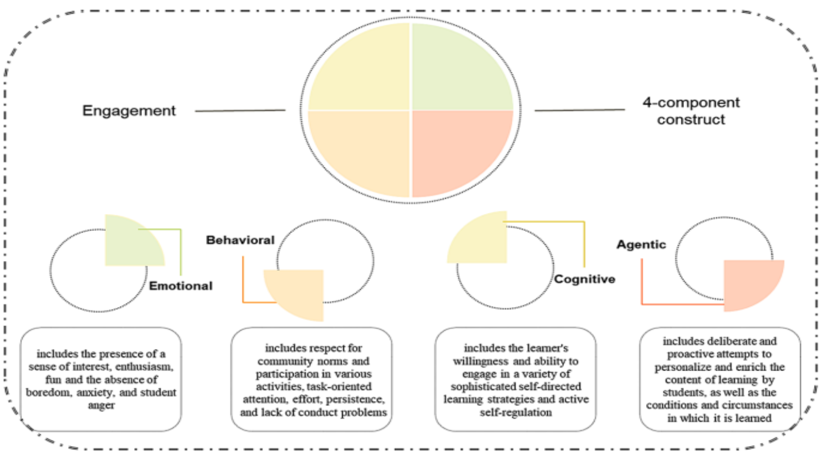


Fig. 1. component of engagement model

In Mathematics Education, it has been observed that taking the leverage of virtual learning resources to engage the learners gears toward curiosity, participation, and the drive to learn more. Thus, virtual learning resources might become a handy tool to promoting meaningful engagements in learning. Virtual environment is an artificial reality of interactive computer based application that provides a way for the user to simulate either the real or imaginary objects, processes or actions. Augmented reality and virtual reality are terms that refer to technological advancements that combine the digital and physical worlds by superimposing digital information over human perceptions of the real environment. On the other hand, they vary based on the fact that VR implies a computer-produced simulation that resembles a real-world experience, whereas AR is more encompassing and integrates the natural-world experience together with content generated by a computer programme. Lucid advantages of VR/AR includes the fact that students benefit from a more immersive and interesting learning experience. It is very helpful to learners that may have difficulty in learning. Students are more likely to learn on their own and become independent. Its makes learning from a distance more interesting and fun. Mixed or Augmented Reality (AR) another version of VR defines Virtual items merged with the real world and interact with one another via technology. AR technology allows actual items and virtual information to be combined in order to improve students' interactions with physical setting and their learning. The application integrates a machine's virtual item into the real environment, distinguishes three-dimensional artificial object space (objects, locations, and so on) and guides the consumer's perception as well as understanding of it. Although virtual resources can be seen as an artificially created phenomena, students perceive the experience as real while participating actively in the learning scenario. If the physical counterpart is unavailable, hazardous, or expensive, virtual reality may be stand in effectively for learning and teaching purpose. The virtual worlds reduces high level risk that could be damaging or consequential in real life situations, even when the users are erroneously acted. Students can also get rapid feedbacks within themselves, or responses from others in the same virtual learning environment. The level of incentive to study that immersion gives, for example, is crucial. Indeed was opted that(Dalgarno and Lee, 2010) immersive learning tools can sharpen the focused attention span of the learner, as demonstrated through neurocognitive simulations (Lin et al., 2013). VLEs provide teachers and students with enormous techno-cultural dimension to visualize and communicate ideas in problem solving which are peculiar to Mathematics Instructional strategies(Freiman, 2020). Virtual Learning resources includes Manipulatives that are constituting component of recently developed Dynamic Geometry Environment (DGE) such as GeoGebra, Cabri Geometry, Cinderella, CalcPlots3D (explorative tools for multivariate calculus), Core-Maths Tools, Maplesoft, Geometer's Sketchpad, Tinkerplots, Fathom, Desmos, and Physics Education Technology (PhET) Interactive Simulations applications (Artigue et al., 2011; Hall and Lingefjärd, 2016). They become veritable tool and represent emerging technological resources integrated into the teaching and learning of Mathematics.

1.2.2 Localization of PhET simulation in indigenous nigerian languages

PhET Interactive simulations are free technology-enabled simulation applets available in web-based and apps-based versions, workable with or without internet connection and downloadable from via https://phet.colorado.edu. PhET Interactive Simulations consists of over two hundred (200) virtual manipulatives (Perkins et al., 2012) used by more than 10 million people for teaching, learning, and research in STEM Education. The PhET project was introduced by a Noble Laureate Carl-Wieman and developed by his Research Group in 2002 at the University of Colorado in United States. PhET interactive simulations provide a dynamics and multiple representation of abstract concept which fosters students commitment and engagement, interest and motivation to learn. The visual representation of objects fosters connections between the concepts, and enhances creativity and transferable skills in learning of Mathematics (Kizito and Hassan, 2024; Moyer-Packenham and Westenskow, 2013). This application software makes learning flexible, adaptive and more personalized, since learners can engage in Mathematics learning activities at anytime, anywhere, and at their own pace. This application promotes scientific inquiry, since users interaction with these tools, give immediate feedback about the effect of the manipulation they made. This allows learners to determine the cause-and-effect relationships and answer scientific questions through engaged-exploration of the simulations in the classroom. The use of PhET Interactive Simulations (sims) in teaching Mathematics reduces Mathematical abstractions to a more concrete form, and helps the learner to internalized and externalized mental models which contributes to meaningful and effective learning of the subject matter in the classroom. PhET sims provides avenue fo appropriate scaffolding of the learning through repetitive-drill-practices, tutorials, and animated simulations of the learning contents which help the students to build a mental framework about concepts(Adams, 2010). The PhET sims provide a balance challenge and little puzzles, clues, fun-like rewards and positive reinforcement that makes learning more game-like oriented and enjoyable.

Interactive PhET simulations are worth even more for marginalized or disadvantaged learners, where digital divides persisted because the application is available in mobile/phone apps accessible with or without internet facilities over a wide geographical area and socioeconomic domains. The application has been translated to local languages across sub-Saharan Africa including five (5) indigenous languages in Nigeria namely; Igbo, Hausa, Yoruba, Efik/Ibibio and Ewe languages. Nigeria as a pluralingual community stands to benefit from the innovation in PhET translation Programme. The program trained over hundred (100) Trusted PhET Translators; instructional designers, Educational Technologist, and STEM educators on how to translate the PhET sims into local languages with classified orthography in different cohorts between the years 2021 and 2023. The Translators Network for African Languages was created in support of the translation project and members are notified when new sims are ready translations. In consequence, the practice of PhET sims translation becomes a continuous project in partnership with the Mastercard Foundation and even up to date. The PhET translation utility enables instructors and learners to switch to translated sims in the application that have textual objects, images, animations, and audio translated in L1 language or local dialect during classroom instruction. Hence, the dynamic nature of the dual version of PhET Interactive Simulations operating in both L1 with L2 Language of instruction (i.e English) expand engaged-adaptation and optimal involvement of the learners while creating an experiential learning environment. This project broadens the scope of functionality of PhET Interactive Simulation as an assistive technological tool that mediates instructional delivery among learners with special needs. The element of localizing virtual resources such as PhET sims promote a situatedl earning environment, preserves the sociocultural milieu, promote digital humanity, and prevents the extinction of indigenous African languages. Localization of virtual learning resources provide alternative means of communicating abstract concepts and breaking complex learning objects through the use of a readily available L1 language which seems familiar to the learners. These enable learners to make new connections with prior experiences, therefore increasing students' interest, motivation, knowledge, and metacognitive skills during learning.

1.3 Theoretical frameworks

1.3.1 Cultural-Historical-Activity Theory (CHAT)

The CHAT framework also known as "activity system analysis" provides a systematic and systemic approach to understanding human activities and interactions in complex real-world environments. The CHAT framework was developed by Vygotsky, Leontev, and Engestrom(Engelbrecht and Borba, 2024; Yamagata-Lynch and Yamagata-Lynch, 2010a,b), and they explained that learning being the development of unique higher cognitive functions(goal or object) occurs through the interdependent relations between the learners (subject) and socio-cultural structure (mediated artefacts, tools or instruments). In Fig. 2, student depict the subject acted upon by the on object in order to transform it using mediating artifacts or instruments to the unique outcomes. In turn, the rules of the system mediate between the subject and the community, and the division of labour mediates between the community and the objects. Engeström referred to these triangular relations as activity system analysis. In activity system analysis, the mediated artifacts and tools connote semiotics, texts, language, notation, digital tools, and more knowledgeable others used to augment or act as resources to the subject.

An arguable tenants of the CHAT framework is that cognitive deficit is as a result of cultural deficit during learning. So the first Language (L1) as a historical mediated tool in the activity system analysis provides a dialectic functions during learning and reduces cultural deficits. This theory supports the synergy between content and language integrated learning, as learning occur when learners dialogue between different languages to complete meaning making process. Envisioning Mathematics as a culturally related knowledge and learning as

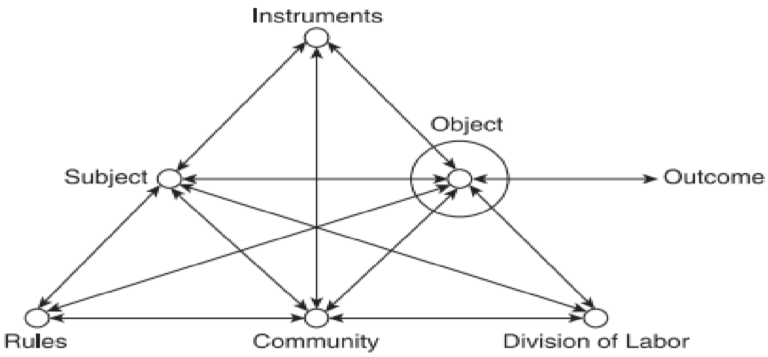


Fig. 2. schematic model of activity system analysis

socioculturally mediated processes expand learners mathematical and cultural identities, and social representations in the classroom. Its becomes pertinent for instructors to seek and maintain cultural cohesiveness by using learners immediate language for instructional purposes because they feel confident using it. Since schools and classrooms become places where teachers, students, and parents are exposed to cultural differences, then teachers should response by integrating the inherent cultural symbols such as language during instructional deliveries. In the lens of post-Vygotskian perspective, explicit mediation has been envisaged as the use of technological tools depicting the notion of "...more knowledgeable and competent others.." and as a tool to shrink the Vygotskian Zone of Proximal Development (ZPD) in Mathematics classroom(Kuhn et al., 2023; Batiibwe, 2019). The ZPD is where the learners' interpersonal and intrapersonal activities blend and fuse and no longer exist as different entities. Hence technological tools such as virtual manipulatives should be use as artifacts to promotes transformational learning in a Mathematics classroom which blends or fused the learners' zone proximal development(ZPD). A further implication of a component of CHAT is the use of virtual manipulative tools as the object of mediation which enhances expansive learning of Mathematics in the classroom. Expansive learning implies learning that leads to an entirely new unit of activity system analysis, with a new object, or problem space. That is, the use of tools, such as language or indeed the computer software, can lead to shifts in the object of the activity after existing contradiction, leading to a new kind of learning which is characterized as expansive in that it leads to new concepts, new agency and a new way of acting in the new activity system. Virtual manipulative as a cognitive tool, transforms pedagogical practices by impacting on division of labour and the object of the activity, with teachers and students taking on different roles and responsibilities during teaching and learning processes(Hardman, 2015).

1.3.2 E-Learning Theory

E-learning theory is a constellation and refinement of Mayer's multimedia instructional design principles (Mayer, 2024) and Sweller's cognitive load hypotheses(Sweller, 2020). In one hand, the multimedia instructional principles connote a systematic process of designing and developing effective and efficient learning experiences through the use of innovative virtual learning resources. On the other hand, cognitive load constructs entail harnessing learners' intrinsic cognitive load to optimize the germane cognitive load, while mitigating extraneous cognitive load during instructional deliveries. The major tenets of e-learning theory is that appropriate instructional design with technological tools and effective usage can create new learning opportunities and promote effective learning. Consequently, e-learning theory explains that by reducing extraneous cognitive load and managing germane and intrinsic cognitive load at an appropriate level of learners' cognitive capacity and through the use of educational technological tools, students can learn effectively and efficiently. The diagram below (Fig.3) show the three types of cognitive loads; intrinsic, extrinsic and germane cognitive load. The antecedent of cognitive loads is derived from the nature of human cognitive architecture. In cognitive science, human cognitive architecture explains that the short-term and working memories are limited in capacity to store information for a long time, and then appropriate secondary knowledge requires strategic and schematic transfer or integration into the long term memory for ease of recall and re-usage. Secondary knowledge yields germane cognitive load, and extraneous cognitive load can be reduced through proper multimedia instructional design principles. It's pertinent for designers of virtual learning environment to conform to these instructional principles; modality, coherence, contiguity, segmenting, redundancy, pre-training and so on. The modality principle state that multiple ways (texts, audio, visuals, and intimations) of information presented to learners reduces extraneous cognitive load. Thus rather than displaying a diagram and written text that rely solely on the visual channel, a diagram and spoken text that rely on audiovisual modalities should be utilized. Also, unnecessary noise brings redundancy in cognitive process which can inhibits understanding in the learning environment. Hence effective instructional resources such as virtual manipulatives should be used to reduce redundant effects in the classroom. Another principle of e-learning is adaptability to the learning environment(see Fig. 3). The implication is that, primary biological knowledge which consists of generic-cognitive skills such as first language(L1)(Sweller, 2020) should be used as an informal communication style to aids the understanding and comprehension of secondary knowledge which uses the formal language of instruction (L2). Other implications of adopting e-learning resources are highlighted in Fig. 3.

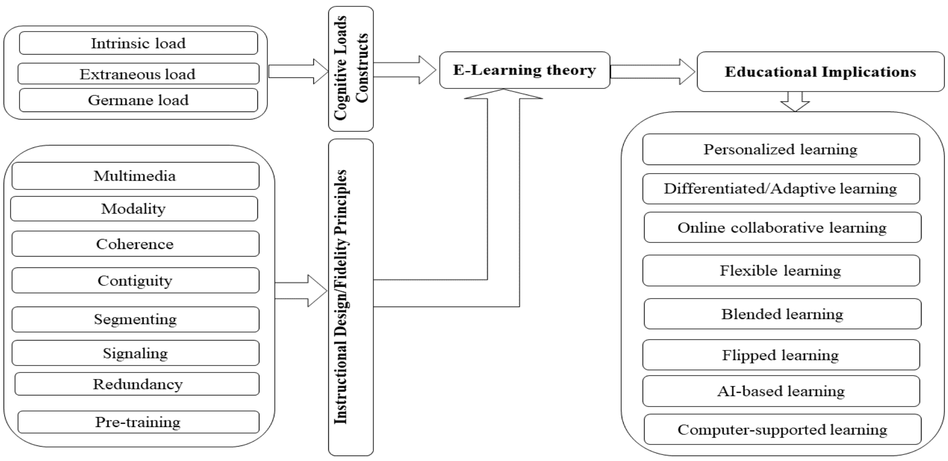


Fig. 3. e-learning theoretic Framework and implications

1.4 Empirical review

Although there are many data-driven research works on PhET Interactive simulations and students' performance, more results are yet to be establish about the effects of localizing PhET Interactive Simulations in Indigenous Nigerian Language. In a study of the effects of virtual manipulatives on students performance and retention in quadratic graphs, PhET Interactive Simulations was used as a virtual manipulative learning strategy (Akpan and Obafemi, 2023). They found out that a virtual manipulative applet in PhET Interactive Simulations used a an instructional aid enhances students' performance and retention of the concept of quadratic graphs. They attributed significant differences in students performance when using PhET sims to the dynamic and interactive features of the application. Also, they found that PhET interactive simulations is gender sensitive, exhibited inclusive features, and they recommended PhET sims to be used as assistive technological tools to augment the teaching and learning of Mathematics. An experimental comparative technique was used to investigate the effectiveness of PhET Interactive Simulation-based activities in improving the Students Academic Performance in Sciences (Mallari and Lumanog, 2020). It was revealed that students' given treatment using PhET Interactive Simulation-based activities performed significantly higher than student taught the same concepts in conventional method. The students' in experimental group proves to be more engaging and motivated to manipulate the learning resources, and these serve as a the antecedents to their improved performances in sciences. There were substantial improvements in students' learning outcomes, motivation and attitude in junior secondary school students in Basic Science subject after using PhET in a simulation-based interactive learning environment (Olugbade et al., 2024). They opted that PhET sims can be utilized as an effective pedagogical tool in science teaching, particularly in developing countries where learning resources could be challenging. PhET Interactive Simulation has been proven to give high level of students' engagement in Physics, and they recommended the use of computer simulations as a valuable tool for enhancing student involvement in Physics Education.

1.5 Statements of the problem

Although, the emergence of smart learning tools has made learners to be technologically savvy, it integration in Mathematics Education in Nigeria seems to be far-reaching. The problem persists deeply in the rural area and among disadvantaged learners, as appropriate remote learning strategies has not been used to augments the routine instructional practices in form of synchronous and asynchronous patterns. The evidence is clear that improvements in proficiency underpin future economic development, and the building of more cohesive and equal societies(Gustafsson, 2021). Thus, localized virtual learning strategy could complement the critical components; effective teaching, suitable technology, and engaged learners which have direct experiential effects on learners proficiency indicators. The translated PhET Simulations into indigenous Nigerian languages in particular efik/ibibio language could ameliorate or reduce the back-log learning loss due to COVID-19 in pursuance of the Recovering Education Agenda(Mazza, 2021). It is pertinent to localized virtual learning tools such as PhET Interactive Simulations and assess the impacts on students proficiency indices or learning outcomes when engaged in the virtual learning environment. On the other hand students' engagement is deeply rooted in Mathematics learning, research and practices, but a substantially valid and reliable engagement measurement scale is lacking. Despite the significance of the engagement concept, the lack of instruments with robust psychometric constructs has hindered adoption of engagement constructs in exploring the relationships of some latent observable constructs and continuous measurable parameters. This study would suggest the utilization of a robust engagement instrument to boosting research in this promising area.

1.6 Purpose of the study

There is a research gap on the investigation of impacts of localization of virtual manipulative; PhET Interactive Simulations on students' engagement in Mathematics. The question, how inclusive is the virtual learning resources? has not been established. The study will establish a valid and reliable but adapted engagement measurement scale. In the same vein, this study seeks to determine the impacts of localization of PhET Interactive Simulations on students' perceived engagements for predicting academic achievements of students in Mathematics in the concept of quadratic graphs. The following research questions and the corresponding null hypotheses will guide the study

1.6.1 Research questions

- What is a substantially reliable engagement measurement scale to assess students' perceived engagements on the use of localized virtual Mmanipulative (PhET Interactive Simulations) in learning the concepts of quadratic graphs in Mathematics?
- What is the impact of localization of PhET Interactive Simulation on students' engagements in predicting academic achievement of students in Mathematics in the concept of quadratic graphs.

1.6.2 Research hypotheses

- There is no significant inter-correlation between the engagement measurement constructs as observed by students taught Mathematics using localizing PhET interactive simulations.

- There is no significant explanatory effect of localization of PhET Interactive Simulation on students' engagements in predicting academic achievements of students in Mathematics.

2 Methodology

2.1 Research design and procedure

This study used a mixed research design method. The participants of the study consisted of senior secondary one (1) students of Efficient secondary school in Uyo, Akwa Ibom state. A purposeful random sampling technique of sample size ($n = 333$) obtained using the modified Cochran's formula (Hasan and Kumar, 2024) given as

$$n_0 = \frac{Nt^2\rho^2}{N + t^2\rho^2} \tag{2.1}$$

where n_0 is the required sample size, N is the population of the study, t is the $t-value$ at the desired probability level of .05 with degree of freedom $N - 1$, ρ is the sample control ratio estimated as a categorical dataset as $\frac{\sqrt{(p(1-p))}}{\epsilon}$, ϵ is the proportion of acceptable error, and ρ is the proportion of presence of an attribute in the population. The sample size was selected based on the criteria that, the school have adequate internet facility and educational resource laboratory and furnished with computer local area networked system. Qualitatively, a a questionnaire entitled Students' Engagement Measurement Scale (SEMS)" in Mathematics was adapted for the study to measure the students' perceived engagement with the localized virtual manipulative (PhET Interactive Simulations). The Questionnaire has 20-items to measure five Engagement constructs; cognitive Engagement, Emotional Engagement, Behavioural Engagement and Agentic Engagement. The components of each factor levels of SEMS of the questionnaire is given in Table 1. The instrument was trial tested on a sample of one hundred (100) students within the target population. The face, and content validity were carried out by research experts in the field of test and evaluation. Students responded using a 4-point Likert scale ranging from strongly agree (4), agree (3), disagree (2), and strongly disagree (4). Similarly, each component factors of the questionnaire yielded internal consistencies, obtained using cronbach's alpha technique; cognitive engagement($\alpha = 0.927$), emotional engagement ($\alpha = .878$), behavioural engagement ($\alpha = .889$), and agentic engagement ($\alpha = .850$). This established a modest reliability indices in this study. The Cronbach's alpha's assumptions of equal factor loading in each constructs underestimates the notion of substantial reliability(Cheung et al., 2024a) and remains unjustifiable for an engagement measurement scale developed in this study.

Table 1. Students' Engagement Measurement Scale(SEMS) in Mathematics

Latent Constructs	Indicators
Cognitive Engagement(COE)	item 1: I interprets mathematical concept using L1
	item 2: I can recall previous mathematical concepts using L1
	item 3: I use mathematical concepts to solve a real life problem
	item 4: I give attention to mathematical concepts taught using L1 and L2
	item 5: I am inquisitive to learn maths concepts using L1
Egentic Engagement(EGE)	item 1: I share mathematical ideas to peers in class using L1
	item 2: I asked questions about Mathematics concept in class using L1
	item 3: I response to answers of mathematics concepts when explained in L1
	item 4: I communicates mathematical concepts to others in class using L1
	item 5: During class, I express my preferences and opinions using L1
Behavioural Engagement(BEE)	item 1: I manipulate maths concepts using localized virtual apps in class
	item 2: I use different skills to solve maths problem when taught in L1.
	item 3: I perform class tasks when taught mathematics using L1
	item 4: I manipulates maths concepts with localized virtual app in my own pace
	item 5: I learn maths concepts individually when taught in L1.
Emotional Engagement(EME)	item 1: I have interest in mathematics when taught using local language
	item 2: Learning mathematics using local language is fun
	item 3: I enjoy learning mathematics using local language
	item 4 I have feelings of self-belonging when taught maths using L1
	item 5: I develop deep self-esteem in mathematics when taught using L1

L1: Local language (Efik/Ibibio) L2: Language of Instruction (English)

An Exploratory Factor Analysis(CFA) was used to obtain convergent and discriminant validity after standardizing the datasets using the formula

$$X_{normalized} = \frac{X_{value} - \bar{X}}{SD_X} \tag{2.2}$$

where X denotes the construct of interest. The convergent and discriminant validities strengthen the assumption that the amount of variance of each indicator captured by a factor is substantial, and no indicator cross-loads(unidimensionality) on any other factor. Thus the composite reliability(CR), average variance extracted (AVE), and discriminant validity were computed using the formulas;

$$\begin{cases} AVE_X = \frac{\sum\limits_{i=1}^{p} \lambda_i^2}{\sum\limits_{i=1}^{p} \lambda_i^2 + \sum\limits_{i=1}^{p} Var(\xi_i)} \\ CR_X = \frac{\left(\sum\limits_{i=1}^{p} \lambda_i\right)^2}{\left(\sum\limits_{i=1}^{p} \lambda_i\right)^2 + \sum\limits_{i=1}^{p} (1-\lambda_i^2)} \\ DV_X = \sqrt{\frac{\sum\limits_{i=1}^{p} \lambda_i^2}{\sum\limits_{i=1}^{p} \lambda_i^2 + \sum\limits_{i=1}^{p} Var(\xi_i)}} \end{cases} \tag{2.3}$$

where p is the number of items called the indicator of named construct X, and λ_i is the completely standardized factor loading of the i^{th} indicator. Since both indicators and constructs are standardized, the value of AVE is equivalent to the average of the square of completely standardized factor loadings across all its indicators. The AVE should was greater than 0.5 to demonstrate an acceptable level of convergent validity, meaning that the latent construct explains no less than 50% of the indicator variance in the study. Also, any CR values greater than or equal to 0.7 depicts a good reliability. In other words, the total error variance consist of less than 30% of the variance of the latent variable. The discriminant validity measurement was obtained as the square root value of the AVE for each construct to ensure unidementality (i.e., each indicator loads uniquely on only one construct).

Quantitatively, the corresponding academic achievement scores of students were obtained after a treatment given to the study sample. This intervention focused on the use of Localized virtual manipulatives (instructional strategy) to teach Mathematics concepts. The Academic achievement test (AAT) was a 20-item multiple choice questions, where correct answers was assigned a numeric value one(1) and wrong answer was assigned the numeric value (0). The instrument had a reliability coefficient ($\alpha = 0.78$), using Kudar-Richadson (KR_{21}). This ensures equal difficulty level for each of the question used. A Regression model is used to analysis and predicts the interrelationship between the dependent variable (academic achievement scores of students taught quadratic graph using Localized Virtual Learning Strategy) and independent variables (Students' Perceived Engagements through the use of Localized Virtual Learning strategy)(Yuduang et al., 2022). Let the response variable y be estimated with an $\mathbf{X}$ matrix of n sample observations and p predictor variables, represented as $\boldsymbol{X_j}$. $\mathbf{X}^T = (X_1, X_2, ..., X_p)$. Then, the i^{th} person's response variable is y_i, modeled by $\boldsymbol{x_i} = (x_{i1}, x_{i2}, ..., x_{ip})^T$ and an error term ϵ. Thus the multiple linear regression model is fitted using the following equations

$$\begin{cases} y = f(\mathbf{X}) = \beta_0 + \sum\limits_{i=1}^{p} X_j\beta_j + \epsilon \\ \beta_i = argmin\left(\frac{\sum\limits_{i=1}^{n}\left(y_i - \sum\limits_{i=1}^{p} x_{ij}\beta_j\right)^2}{2}\right) \\ R^2 = 1 - \frac{\sum\limits_{i=1}^{n} (\hat{y}-y_i)^2}{\sum\limits_{i=1}^{n} (\bar{y}-y_i)^2} \\ R_{adj}^2 = 1 - \frac{(1-R^2)(n-1)}{n-p-1} \end{cases} \tag{2.4}$$

3 Analytics

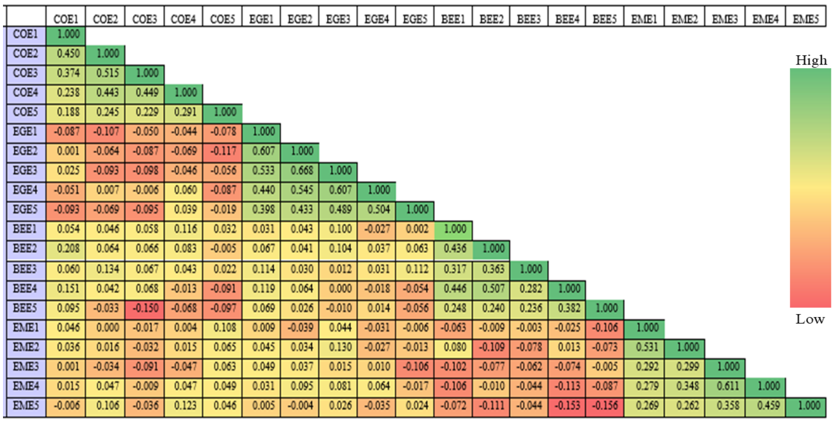
3.1 Validation and reliability of engagement measurement constructs using EFA

This section answers research question 1 and hypothesis 1, which seek to ascertain the validity and reliability of an engagement measurement scale. The appropriateness of the Engagement measurement variables and latent constructs supported the use of Exploratory Factor Analysis (EFA), since the measure of sample adequacy (KMO =.725) was higher than 0.5, and Bartlett's test of sphericity($\chi^2 = 1955.26, p < .00001$) is significant as shown in Table 2. Hence the sample data-set is adequate for a factor analysis.

Table 2. KMO-Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.725
Bartlett's Test of Sphericity	Approx. Chi Square	1995.25
	df	190
	Sig.	.00001

To ensure that the latent variables are highly inter-correlated within each major constructs; Cognitive Engagement (COE), Egentic Engagement (EGE), Behavioural Engagement (BEE), and Emotional Engagement, the heat-map of correlation between the latent constructs is given below in Fig. 1. For a substantial validation of the measurement datasets, factor loadings of the engagement constructs was extracted using principal axis factoring, and promax rotation with Kaiser normalization. Using the criteria in (Tavakol and Wetzel, 2020), factor loadings with absolute values (< 0.4) was suppressed, and four (4) observed factor levels were extracted to determine convergent and discriminant validities of the engagement measurement scale as shown in Table 3. All the items in egentic engagement was loaded in factor 1, items loaded in factor 2 were responses on emotional engagement, factor 3 was loaded with items on cognitive engagement, while factor three was loaded with behavioural engagement. All factor loadings were higher that 0.4, as shown in Table 3 and following the criteria in (Gupta and Nagpal, 2021; Cheung et al., 2024b), this shows a good correlation within each item in its corresponding factor with 62.89% as the average variance extracted from the latent constructs.



	COE1	COE2	COE3	COE4	COE5	EGE1	EGE2	EGE3	EGE4	EGE5	BEE1	BEE2	BEE3	BEE4	BEE5	EME1	EME2	EME3	EME4	EME5
COE1	1.000																			
COE2	0.450	1.000																		
COE3	0.374	0.515	1.000																	
COE4	0.238	0.443	0.449	1.000																
COE5	0.188	0.245	0.229	0.291	1.000															
EGE1	-0.087	-0.107	-0.050	-0.044	-0.078	1.000														
EGE2	0.001	-0.064	-0.087	-0.069	-0.117	0.607	1.000													
EGE3	0.025	-0.093	-0.098	-0.046	-0.056	0.533	0.668	1.000												
EGE4	-0.051	0.007	-0.006	0.060	-0.087	0.440	0.545	0.607	1.000											
EGE5	-0.093	-0.069	-0.095	0.039	-0.019	0.398	0.433	0.489	0.504	1.000										
BEE1	0.054	0.046	0.058	0.116	0.032	0.031	0.043	0.100	-0.027	0.002	1.000									
BEE2	0.208	0.064	0.066	0.083	-0.005	0.067	0.041	0.104	0.037	0.063	0.436	1.000								
BEE3	0.060	0.134	0.067	0.043	0.022	0.114	0.030	0.012	0.031	0.112	0.317	0.363	1.000							
BEE4	0.151	0.042	0.068	-0.013	-0.091	0.119	0.064	0.000	-0.018	-0.054	0.446	0.507	0.282	1.000						
BEE5	0.095	-0.033	-0.150	-0.068	-0.097	0.069	0.026	-0.010	0.014	-0.056	0.248	0.240	0.236	0.382	1.000					
EME1	0.046	0.000	-0.017	0.004	0.108	0.009	-0.039	0.044	-0.031	-0.006	-0.063	-0.009	-0.003	-0.025	-0.106	1.000				
EME2	0.036	0.016	-0.032	0.015	0.065	0.045	0.034	0.130	-0.027	-0.013	0.080	-0.109	-0.078	0.013	-0.073	0.531	1.000			
EME3	0.001	-0.034	-0.091	-0.047	0.063	0.049	0.037	0.015	0.010	-0.106	-0.102	-0.077	-0.062	-0.074	-0.005	0.292	0.299	1.000		
EME4	0.015	0.047	-0.009	0.047	0.049	0.031	0.095	0.081	0.064	-0.017	-0.106	-0.010	-0.044	-0.113	-0.087	0.279	0.348	0.611	1.000	
EME5	-0.006	0.106	-0.036	0.123	0.046	0.005	-0.004	0.026	-0.035	0.024	-0.072	-0.111	-0.044	-0.153	-0.156	0.269	0.262	0.358	0.459	1.000

Fig. 4. Heat map of inter-related engagement measurement scale

Although the cronbach's alpha reliability indices were higher than the required threshold value of 0.7 across all factors as shown in Table 3, its neglected sampling error in the measurement, and the assumptions of equal factor loadings (tua-equivalence) in each latent construct underestimate the overall substantial reliability of the engagement measurement scale as adapted. The frequent misuse of Cronbach's alpha may be attributable to

Table 3. Exploratory factor analysis of engagement measurement Scales

Engagement Constructs	Item indicators	F_1	F_2	F_3	F_4	CA	AVE	CR	DV
Egentic Engagement(EGE)	EGE3	.911				.85	0.73	.93	.852
	EGE4	.910							
	EGE2	.902							
	EGE1	.777							
	EGE5	.747							
Emotional engagement(EME)	EME4		.845			.878	.620	.89	.787
	EGE3		.831						
	EGE2		.792						
	EGE5		.741						
	EGE1		.716						
Cognitive Engagement(COE)	COE2		.823			.927	.610	.89	.780
	COE3			.800					
	COE4			.800					
	COE1			.789					
	COE5			.661					
Behavioural Engagement (BEE)	BEE4				.923	.889	.540	.86	.735
	BEE4				.776				
	BEE4				.750				
	BEE4				.719				
	BEE4				.406				
Factors inter-correlation	F_1	(.852)							
	F_2	-.23*	(.787)						
	F_3	-.35	-.213*	(.780)					
	F_4	-.086	.389*	-.314*	(.735)				

significant at 0.01, level F_i(i=1,2,..,4) as factors, CA = Cronbach's Alpha, AVE = Average Variance Extracted, CR = Composite reliability, DV = Discriminant Validity

several factors: (a) unawareness of the problems of Cronbach's alpha (Dunn et al., 2014), (b) easy estimation of Cronbach's alpha using commonly-available statistical software packages, (c) widely-accepted standards for evaluating the adequacy of Cronbach's alpha, and (d) requests from reviewers and/or editors for Cronbach's alpha, resulting in its inclusion in manuscripts.Hence a convergent and discriminate validities of the engagement measurement scale were computed using the standardized factor loadings of the latent constructs. The Average variance extracted (AVE) for the four (4) factors ranged from 0.54 to 0.73 (shown in Table 3) which indicates a good convergent validity as AVE values are more than 0.50. Observe that the square root of AVE values for each construct, as indicated in table are all higher than their corresponding factors inter-correlation coefficients, indicating sufficient differentiation among constructs and supporting the fulfillment of discriminant validity criteria. The confirmation of discriminant validity ensures that there is no significant overlap and redundancy among these constructs, which is crucial during establishing an accurate measurement scale for both quantitative and qualitative analysis. Also, the engagement measurement scale has a good congeneric reliability with values higher that 0.7 referred to as construct validity (CV).

3.2 Regression Model

This section is used to answer research questions (2 and 3) and hypotheses (2 and 3) respectively. The Levene's test of homogeneity of variance was conducted on the engagement measure scale, and its satisfies the normality assumption, as shown in Table 4, which ensured the use of parametric test statistic.

The regression model in Table 5 shown that students' engagements in localized virtual resources predicted significant impacts on academic achievements in Mathematics [$F(4, 328) = 16.86, p < .05$].

Table 4. Levene's Test of Homogeniety of Error Variance

Engagement Measurement Constructs	Descriptive Measures	Levene's Statistic	df_1	df_2	Sig.
	Based on Mean	.895	3	1325	.443
	Based on Median	1.124	3	1328	.338
	Based on adjusted median and df	1.124	3	1325	.338
	Based on trimmed mean	1.087	3	1328	.354

Null hypothesis: there is equality of error variance between the engagement measurement scales.

Table 5. ANOVA of students' engagements and academic achievement in mathematics

Measurement Model	Sum of Squares of Measurement Model	df	Mean Measure	F-ratio	Sig.
Regression	1173.10	4	293.27	16.86	.0001
Residual	5706.13	328	17.40		
Total	6879.23	332			

Dependent variable: Academic Achievement. Predictors: (constant), (EGE), (EME), (COE), and (BEE).

Similarly, the engagement constructs that accounted for the significant impacts in predicting academic achievement of students in Mathematics after using the the localized virtual learning resources has been shown using the unstandardized (β) coefficient in Table 6.

Table 6. Beta-coefficients of the engagement measurement constructs

Model	Unstandardized (β)	Standardized (β)	t	Sig.	Lower bound	Upper bound
Constant	6.07		3.00	0.003*	2.09	1.27
Cognitive(COE)	.67	.12	2.19	.029*	.07	1.98
Egentic (EGE)	2.113	.37	7.12	.000*	1.53	2.7
Behavioural (BEE)	.96	.15	2.71	.007*	.26	1.66
Emotional (EME)	1.35	.22	4.19	.000*	.72	1.98

* = significant at 0.05 level.

Dependent variable: Academic Achievement. Predictors: (constant), (EGE), (EME), (COE), and (BEE).

Cognitive engagement (COE) has shown a statistically significant relationship with the corresponding academic achievement scores of students in Mathematics [β = .67, t(3) = 2.19, p= .029]. The beta coefficient shown that academic achievement increases by .67 unit for every unit increase in the cognitive engagement or mental activities of the students with the localized virtual learning resources. Egentic engagement yielded the highest predictive evidence in the model. Its connotes exploratory input and contributions of learners to the use of local language in the learning environment and has shown a statistically significant relationship with the corresponding academic achievement scores [β = 2.11, t (3) = 7.12, p = 0.000]. Behavioral engagement (BEE) which includes social interactions with peers and the learning environment has shown a statistically significant relationship with student academic achievement in Mathematics [β = .96, t(3)=2.71, p = .007], because first language (L1) has been integrated into the virtual learning environment through the localization of interactive simulations of PhET. Emotional engagement (EME) or students' empathetic understanding yielded a statistically significant relationship and predicts corresponding increase in students academic achievement score in Mathematics [β = 1.35, t(3) = 4.19, p = .000].

3.3 Discussion

This study provides substantial insights into the interrelationships that exist among engagement measurement scales and adapted a valid and reliable students' engagement indicators to measure students' perceived engagement with localized virtual learning application in Mathematics. The report is in line with (Li and Li, 2024), because the understanding of students' engagement components and interact can influence the crucial advancement and integration of technology to Mathematics Education. Empirically, the study demonstrates the positive impact of students' engagement in language and content integration as predictors of students' academic achievement and learning outcomes. According to the review(Kaphesi, 2001), Mathematics tension and the dreaded perception of the difficulty in the subject matter can be reduced through the integration of sociolinguistic approaches in the teaching and learning of the subject. In support of the findings in this study, it has been reiterated that first language is a sociocultural and situated learning tool that fosters competence in mathematical communication (Moschkovich, 2002).

In this study, students' agentic engagement in localized learning resources yielded the highest predictable value of increase in academic achievements or learning outcome in Mathematics. This finding underscore the fact that students' agentic engagement skills and indicators such as sharing mathematical ideas to peers in class using L1, asking questions about Mathematics concept in class using L1, responding to answers of mathematics concepts when explained in L1, and communicating mathematical concepts to others in class using L1, foster a great potential in terms of enhancing learning outcomes. This is in line with the previous study in (Maričić et al., 2023b), as they emphasized that agentic engagement makes learning environment more personalized, interesting, and develeop students mindset to constructively contribute meaningfully to learning of Mathematics. In order to facilitate agentic engaging classroom, teachers should make learning supports for learners to be free and autonomic as they strive to exercise optimal engaging effort in the classroom (Maričić et al., 2023a).

Also the findings of this study indicated that students' learning outcomes are predictable by their emotional engagement in the classroom. Seeking learning scenarios that reduces boredom while promoting interactivity to elicits joy, and fun-like moments in the classroom are variables that improve students' academic achievement in Mathematics. This is similar to a study seen in (Nor et al., 2016) on relationship between emotional intelligence and mathematical competency among secondary school students. They opted that teachers' emotional intelligence can reduce the fear, anxiety and the dreaded perception of students about Mathematics, which translates to improvement in academic achievement of students in Mathematics. A previous study reported similar findings, that digital learning tools that are mediated by motivation-emotional-engagement in the learning environment promotes learning outcome in Mathematics classroom(Oppmann and Zhang, 2023).

This study shown that behavioural engagement such as students' manipulative skills, sustained attention and persistence in performing classroom tasks and use of local language have direct consequences on their academic achievements. This underscore the finding presented in a study on students' behavioral engagement during mathematics educational video game instruction(Tharp, 2024). They observed that behavioural engagement such as focus attention, and persistence are associated with better performance on an assessment of the skills being taught in Mathematics game-like learning environment. New evidence has been reported in(Crockett and Snow, 2022), that behavioral engagement affects the growth of student achievement at multiple levels; within the individual, in the classroom environment, and the interaction of the individual and the classroom environment, all related to math results.

The study shown that cognitive engagement is a direct measure of students' academic achievement in mathematics. The provisions for learning, interpretation of mathematical expressions and symbols using a more familiar local dialect create mental patterns and establish cognitive schema and networks between primary (intrinsic) and secondary (learned) knowledge of mathematics. This is supported in the report by (Joshi et al., 2022). They observed that cognitive engagement promotes self-regulated deep learning strategies, higher-order thinking skills, frequent and interactive engagement for internalization and externalization of Mathematical concepts.

4 Conclusions

This study established a valid and reliable engagement measurement scale used to measure students' perception of impact of localization of virtual manipulatives for teaching and learning of Mathematics. This is a predictive model that assesses the significant relationships between student engagement in interactive PhET simulations that have been translated into the indigenous language (efik/ibibio) in Nigeria for flexible learning in STEM

Education. The relationships between the behavioural, social, cognitive, and emotional engagement were found to be significant. These demonstrated the fact that increase in any type of engagement is consequential to increase in students' academic achievement in Mathematics, when taught using localized virtual learning tools. Thus, the assessment of students' engagement in innovative digital learning tools that facilitate situated and experiential learning of mathematics underscores seamless learning of Mathematics concepts. In this study various empirical evidence have shown that the integration of socio-cultural relevance and first-order language with virtual learning tools can facilitate students' engagement in learning Mathematics with a direct improvements on students' academic achievement in Mathematics concepts.

Disclaimer (Artificial Intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Code Availability

Access to PhET HTML5 translation utility was granted by the Deputy Director of PhET Interactive Simulation Prof. Rebecca E. Vieyra, of the University of Colorado Boulder, USA. The PhET translators' utility portal is strictly for trusted and certified PhET translators. One(1) published simulation (trig-tour) and five (5) unpublished sims were translated into efik/ibibio langauge and used for the study.

Data availability and transparency

All data and materials as well as software applications or custom code support published claims and comply with field standards. The data generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations for Ethical Approval

All procedures followed were in accordance with the ethical standards and principles for conducting a research in the institution. All research participants were guaranteed anonymity.

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Competing Interests

Authors have declared that no competing interests exist.

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