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Web Metrics and Key Performance Indices of the Villagemath Instructional Content Repository

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Abstract: This study presents the outcomes of common web metrics and key performance indices of VillageMath, an online culture-based Instructional Content Repository for STEM learners and teachers. The study adopts a developmental research design. The developed intervention is accessible at https://villagemath.net. Data collection on common web metrics and key performance indices (KPIs) was handled using standard web performance assessment tools such as WP Statistics, Pingdom Tools, Google PageSpeed Insights, GTmetrix, and WebPage Test. The metric platforms were chosen based on their industry standing, ease of use, and the wide range of KPIs that they measure. The metrics provide a median run performance result accounting for Time to First Byte (when did the content start downloading?), Start Render (when did pixels start to appear?), Speed Index (how soon did the page look usable?), Cumulative Layout Shift (how much did the design shift while loading?), Page Weight (how many bytes downloaded?), speed (from 7 different locations on five continents strategically placed around the globe), total page size, and suggestions for improvement. The data collected was analysed using descriptive statistics such as tables, charts, and averages. The analysis of results obtained from the web performance assessment tools indicated that the web-based VillageMath Repository appeals to a wide range of highly engaged users. Key performance indicators such as speed index, page size, and last painted hero for the VillageMath Instructional Content Repository were above industry averages and affirmed that the platform is robust, elegantly designed, and fast.

Keywords: STEM education, VillageMath, web metrics, key performance indices, ethnomathematics.

1. Introduction

At the classroom level, successful technology integration is achieved when technology is used regularly and seamlessly, making it easily accessible and readily available for the task at hand. This integration should support the curricular goals and help students effectively achieve their personal goals (Edutopia, 2007). Technology augmentation aims to incorporate technological tools into the learning process so seamlessly that they become almost second nature in ordinary classroom activities. When learners have easy access to these tools and they are effectively incorporated into instructional activities, the result is often active engagement and an opportunity to develop a deeper understanding of the instructional content (Agbo-Egwu, Abah & Abakpa, 2018; Abah, Anyagh & Age, 2017).

One of the ways digital technologies are aiding present-day education is by serving as a vehicle for relaying instructional content. Specific areas of quantifiable success in this regard include ICT-based instructional approaches, implementation of open and distance learning (ODL), online instructional repositories, and circulation of open education resources (OERs) (Iji & Abah, 2018). Leading the pack in ODL, for instance, are the Massive Open Online Courses (MOOCs), designed for a large number of participants, that can be accessed by anyone anywhere if they have an internet connection, are open to everyone without entry qualifications, and offer a full/complete course experience online for

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free (Home & OpenupEd, 2015). Online instructional repositories and OER platforms are a commonplace for enhancing conversation and collaboration in a mathematical community. In such an online learning environment, diversity-bridging tools would include email, bulletin boards, forums, chat groups, and conferencing (Iji & Abah, 2018). The introduction of other new technologies like the virtual classroom and social media makes it possible to replicate technology-based instructional experiences within and outside the classroom (Hofmann, 2014), particularly via the design of web-based applications (or WebApps).

Presently, there exist many instructional content repositories on the World Wide Web (WWW), but only a few are solely dedicated to culture-based Science, Technology, Engineering, and Mathematics (STEM) education. Conventional Mathematics platforms such as Math.com, Mathplanet.com, BasicMathematics.com, Mathplayground.com, SOSmath.com, and Youcubed.org are built to encompass a wide range of content. Familiar contents hosted on these websites include blog articles, mathematical games, videos, teacher guidelines, student workbooks, and mock tests. Additional services offered by these sites include Mathematics tutor service, specialised curriculum, consultancy services, and marketing of educational products. The target audiences of these conventional Mathematics repositories are often teachers and students of Mathematics across different grades and educational levels. A few of these sites require users to register as either students or teachers to have full access to the functionality of the platform. But none of these platforms provides a dedicated repository for culture-based mathematics education, a gap that VillageMath intends to fill.

Culture is a learned behavior consisting of thoughts, feelings, and actions and is transferred in social interaction (Walsh, Vainio & Varsaluoma, 2014). Within every culture, there exist indigenous knowledge which encompasses the complex, intergenerational, and cumulative experiences and teachings of the indigenous peoples (Jacob, Sabzalian, Jansen, Tobin, Vincent & LaChance, 2018). However, many contemporary educational researchers agree that there is a discontinuity between the home or community culture of students and the education they receive in mainstream schools (Ezeife, 2011). The lack of relevance of school Mathematics to the learners' everyday life and culture suggests that there is a need to incorporate into the mathematics curriculum such cultural practices, ideas, and beliefs that would connect the school to the community in which it exists and functions. Educators, academics, and policymakers have called for more research that addresses gaps in understanding of culture-based Mathematics Education (Kanaiaupuni, 2007).

Culture-based Mathematics Education is the teaching and learning of Mathematics that takes into consideration the context of the learners, blending academic and vocational competencies. Contextualisation is based on the proposition that people learn more effectively when they are learning about something that they are interested in, that they already know something about, and that affords them the opportunity to use what they already know to figure out new things (Epper & Baker, 2009 and CUNY, 2003). The use of locally relevant contexts - situations and phenomena that have local and personal meaning to students and teachers for whom a curricular product is designed - provides access to educational and social participation and opportunity at multiple levels of practice (Ebby, Lim, Reinke, Remillard, Magee, Hoe & Cyris, 2011). In other words, Culture-based Mathematics Education, in addition to attending to academic goals, must take seriously the ways students' experiences are structured by policies, institutions, and societal practices and work with students to confront them.

Evidently, new tools and media can be extremely helpful to many mathematics teachers who would otherwise struggle to provide culture-based mathematics instruction. If schools are to provide such forms of instruction effectively and at scale, they will require a new technology infrastructure such as e-learning (Dede, 2014). E-learning can be defined as the use of computer and Internet technologies to deliver a broad array of solutions to enable learning and improve performance (Ghirardini, 2011). However, e-learning is a cultural artifact and as such, it is infused with characteristics that reflect those of the designing culture. In other words, any e-learning application will possess characteristics that reflect the culture of its originators and users, from the types of pedagogies they prefer to their cultural expectations and values (Masoumi & Lindstrom, 2009). Accepting this view that culture is an integral part of every aspect of instructional design makes it important to consider social and cultural differences in designing and providing mathematics education and instruction.

Bringing culture to the nexus of discussions and enactments (that is, what people do and how they do it) in designing e-learning and seeking to align teaching and instruction to the cultural contexts of ethnically diverse learners challenges mainstream notions of teaching and learning (Masoumi & Lindstrom, 2011). Cross-cultural design is designing technology for different cultures, languages, and economic standings, ensuring usability and user experience across cultural boundaries (Walsh, Vainio & Varsaluoma, 2014). Such a user-centered design approach supports the cross-cultural product development process with user-centered activities identifying the need for internationalisation and localisation.

In the field of instructional technology, "development" has a unique connotation. The most current definition views "development" as the process of translating the design specifications into physical form (Richey, Klein & Nelson, 2004). In other words, it refers to the process of producing instructional materials, interventions, and even web-based products. On this premise, design-based research (DBR) methods focus on designing and exploring the whole range of designed innovations: artifacts as well as less concrete aspects such as activity structures, institutions, scaffolds, and curricula (The Design-Based Research Collective, 2003). Interventions such as web-based educational products embody specific theoretical claims about teaching and learning and reflect a commitment to understanding the relationships among theory, designed artifacts, and practice.

Basically, design-based research is a process that integrates design and scientific methods to allow researchers to generate useful products and effective theory for solving individual and collective problems of education (Easterday, Lewis & Gerber, 2014). The design and DBR processes consist of six (6) iterative phases in which designers focus on the problem, understand the problem, define goals, conceive the outline of a solution, build the solution, and test the solution. Following this blueprint, mathematics education researchers like Mosimege (2004) report outcomes of a South African program that calls upon curriculum planners and implementers to incorporate indigenous knowledge systems aspects within Mathematics. The extent to which mathematical knowledge is exhibited in cultural villages in both the workers and the artifacts made was discussed in line with how these can be used in mathematics classrooms. Mosimege (2004) lists mathematical concepts identified in the making of a grass container and the beadwork to include estimation, lines, shapes, patterns, and angles.

Further design-based studies have shown that culture-based mathematics education can have significant positive effects for students, including improved retention, graduation rates, college attendance rates, and standardised test scores (Best & Dunlap, 2013). Fenyvesi, Koskimaa, and Lavicza (2014) show that creating visual illusion, paradox structures, and "impossible" figures through playful and artistic procedures holds an exciting pedagogical opportunity for raising students' interest towards mathematics. To anchor this, innovating designed games were deployed to clarify mathematical concepts behind and related to visual illusions, such as symmetry, perspective, and isometric projection (Fenyvesi, Koskimaa & Lavicza, 2014).

Relatedly, Neel (2010) carried out a study in the culture-based mathematics instructional design paradigm in which members of the Haida Role Model Program on the islands of Haida Gwaii were interviewed to determine how they "Do the Math" in their daily lives. The program "consists of elders, professionals, and community members that go to schools and assist teachers in integrating Haida knowledge and perspective with the school curriculum. The Role Models provide a vital connection between the school district community and the Haida community. The outcomes of the instructional design show that the mathematical practices in the community life of Haida Gwaii are unique to its people, land, and context. The culture-based intervention was useful in integrating students' experiential Mathematics with their school mathematics, for the purpose of helping them to be motivated and make new connections to improve achievement. This disposition proves that Mathematics is useful and meaningful for indigenous students by showing them how traditional and contemporary cultural activities have many mathematical concepts embedded in them. Neel (2010) reports that broadly, ability to learn Mathematics increases when the students are taught skills that are useful for their daily functioning in the home, the workplace, and the community. A similar approach was used by Francoise, Mafra, Fantinato, and Vandendriessche (2018) to design culture-based mathematics instruction involving string figure making and handcrafted calabash gourd, with the outcome affirming that out-of-school practices are dynamic in nature and performed along an informal-formal learning continuum. These innovative dimensions to mathematics education require showcasing to a wider range of users and audiences via a web-based ethnomathematics instructional content repository.

VillageMath is a web-based ethnomathematics content repository that promises individualised learning in a widely connected educational cloud. The range of intended resources available on the platform seeks to achieve a custom-made, web-based product for Mathematics education practitioners from all over the world. The cultural foundations of Mathematics that are the fulcrum of the development of the website are intended to draw users to a one-stop reservoir of online resources that are tailored to the peculiarities of Mathematics education as a field of practice.

With every online tool, there is a concern for quality, specifically in the context of web-based tools. Quality in this regard is related to customer satisfaction and the ability of a website to meet user expectations. It encompasses subjective aspects of the user-website interaction, focusing on the emotional and cognitive experience of the user community. This emphasis on quality is vital to assessing user satisfaction and ultimately contributes to the overall evaluation of website quality, which combines objective metrics with subjective user feedback (Moustakis, Litos, Dalivigas & Tsironis, 2004).

By utilising various web analytics metrics such as the number of visits and visitors, as well as visit duration, it is possible to develop Key Performance Indicators (KPIs). KPIs provide a versatile analytical model for comparing different metrics and identifying visitor trends (Booth & Jansen, 2010). These dynamic numbers provide a comprehensive understanding of visitor behavior on a website, which enables web-based educational platforms to align their goals with their intentions. This alignment facilitates the identification of areas for improvement, promotion of popular sections of the site, testing of new functionality, and ultimately achieving the desired impact.

In a broad sense, an index (plural: indices) is an aggregation of two or more indicators. The distinction between an indicator and an index can be vague and unnecessary since both are often aggregates of variables themselves. The difference between the two lies in the level of aggregation, with an index usually being a scaled composite variable. An indicator, on the other hand, is a single measure. An index is typically a composite that combines indicators through methods such as weighted averaging. Additionally, an index can be any type of summary measure used to capture a specific property, such as engagement, frequency, or speed, in a single number. It is important to note that the use of one index does not exclude the possibility of utilising others. Indicators can be qualitative or quantitative variables used for measuring change, while indices are compound or composite indicators. For example, "PageSpeed" is an index that can be measured using various indicators, including "First Contentful Paint," "Speed," "Time to Interactive," and "First Meaningful Paint," among others. A webtool's key performance indicators (KPIs) are specific, quantifiable metrics used to measure the performance, effectiveness, and success of the designed tool. KPIs provide information on how well the developed intervention is achieving its goals, driving traffic, engaging users, generating leads, and attaining set targets. They serve as crucial benchmarks that allow developers and analysts to gauge a platform's success and health. Vaiciunaite (2022) states that website KPIs are quantitative measurements that help identify the effectiveness of initiatives, examine experiments, and track goal progress by ascertaining how certain initiatives contribute to set objectives and deliverables. Data from KPIs helps when making changes and optimising strategy.

For an educational repository such as VillageMath, an assessment of KPIs is necessary to ascertain the reach, assess quality, and improve content delivery. Studying VillageMath's KPIs is significant to maintain the right level of audience acquisition, behavior, and conversion of intended users from across the globe. This present study, particularly, seeks to project the progress made in the development of the VillageMath Instructional Content Repository since the web-based intervention was built in 2019, as a follow-up to other recent VillageMath quality assessment reports (Abah, Iji, Abakpa & Anyagh, 2021; Abah, 2024). The objective of the present study's KPI assessment is not to determine VillageMath's competitive standing with respect to countless websites out there, but primarily to measure the platform's health and performance as a unique ethnomathematics content repository over the past year.

1.1 Research questions

The following questions were raised to guide this study.

- What is the system specification of the VillageMath instructional content repository?
- What are the statistics of common web metrics of the VillageMath instructional content repository?
- What is the WebPageTest median run performance result of the VillageMath instructional content repository?
- What is the Pingdom Tools performance grade of the VillageMath instructional content repository?
- What is the Google PageSpeed Insight score of the VillageMath instructional content repository?
- What is the GTmetrix Speed Index of the VillageMath instructional content repository?

2. Theoretical Framework

The theoretical foundation for the design of VillageMath is the Cleanroom Software Engineering model (CSEM) (Miles, Dyer & Linger, 1987). The Cleanroom Philosophy was first proposed for software engineering by Mills, Dyer, and Linger during the 1980s. This approach combines conventional software engineering modeling, program verification (correctness proofs), and statistical software quality assurance (SQA) to develop high-quality software products. CSEM emphasises the importance of building correctness into software during the development process, as opposed to the traditional analysis, design, code, test, and debug cycle (Linger, 1994).

When software products fail in the real world, they can pose immediate and long-term hazards. These hazards may be related to human safety, economic loss, or the effective operation of business and societal infrastructure. Cleanroom software engineering is a process model that aims to eliminate defects before they can cause serious hazards (Pressman, 2005). The CSEM process emphasises rigor in specification and design, and formal verification of each design element using mathematically based correctness proofs. In addition to formal methods, the cleanroom approach also includes techniques for statistical quality control, such as testing based on the anticipated use of the software product by users. The model achieves statistical quality control in software development by strictly separating the design process from the testing process in a pipeline of incremental software developments.

In the cleanroom strategy, small independent software teams develop a "pipeline of software increments" (Linger, 1994). Each increment is certified and then integrated into the whole system, allowing the system's functionality to grow over time. The sequence of cleanroom tasks for each increment includes increment planning, requirement gathering, box structure specification, formal design, correctness verification, statistical test planning, statistical use testing, and certification (Pressman, 2005).

The sequence of cleanroom tasks for each increment is illustrated in Figure 1 and Figure 2. Once functionality has been assigned to the software element of the system, the cleanroom increment in the pipeline is initiated. The following tasks occur:

- *Increment Planning:* In software development, there may be a compelling need to provide users a limited set of software functionality quickly and then refine and expand on that functionality in later software releases. The strategy delivers a series of releases called increments that provide progressively more functionality for the user as each increment is delivered. At the onset of the cleanroom process, a project plan that adopts the incremental strategy is developed. The functionality of each increment, its projected size and a cleanroom development schedule are created. Special care must be taken to ensure that certified increments will be integrated in a timely manner.
- *Requirements Gathering:* Using research gathering techniques, a more detailed description of user-level requirements (for each increment) is developed. Requirements gathering provides the appropriate mechanisms for understanding what the end-user wants, analysing needs, assessing feasibility, negotiating a reasonable solution, specifying the solution unambiguously, validating the specification and managing the requirements as they are transformed into an operational system. The task of requirement gathering is accomplished through the execution of seven distinct functions: inception, elicitation, elaboration, negotiation, specification, validation, and management.
- *Box Structure Specification:* A specification method that makes use of box structures to isolate and separate the creative definition of behaviour, data and procedures at each level of refinement (Hevner & Mills, 1993). Basically, a “box” encapsulates the system (or some aspect of the system) at some level of detail (Pressman, 2005). Through a process of elaboration or stepwise refinement, boxes are refined into a hierarchy where each box has a referential transparency. That is, “the information content of each box specification is sufficient to define its refinement, without depending on the implementation of any other box” (Linger, 1994). This enables the analyst to move from essential representation at the top to implementation-specific detail at the bottom hierarchically. The three types of boxes used at this stage are black box, state box and clear box.
- *Formal Design:* Using the box structure approach, cleanroom design is a natural and seamless extension of specification. Although it is possible to make a clear distinction between the two activities, specification (called black boxes) is iteratively refined (within an increment) to become analogous to architectural and component-level designs (called state boxes and clear boxes, respectively).
- *Correctness Verification:* The cleanroom team conducts a series of rigorous correctness verification activities on the design and then the code. Verification begins with the highest-level box structure (specification) and moves toward design detail and code. The first level of correctness verification occurs by applying a set of “correctness questions” (Linger, 1988). If these do not demonstrate that the specification is correct, more formal (mathematical) methods for verification are used.
- *Statistical Test Planning:* The projected usage of the software is analysed and a suite of test cases that exercise a “probability distribution” of usage is planned and designed (Pressman, 2005). Referring to Figure 1, this cleanroom activity is conducted in parallel with specification, verification, and code generation.

- *Statistical Use Testing:* Since exhaustive testing of computer software is impossible, it is always necessary to design a finite number of test cases. Statistical use techniques execute a series of tests derived from a statistical sample (the probability distribution noted earlier) of all possible program executions by all users from a targeted population. Specifically, statistical use testing "amounts to testing software the way users intend to use it" (Linger, 1994). To accomplish this, cleanroom testing teams (also called certification teams) must determine a usage probability distribution for the software product. The specification (black box) for each increment of the software is analysed to define a set of stimuli (inputs or events) that cause the software to change its behaviour. Based on interviews with potential users, the creation of usage scenarios, and a general understanding of the application domain, each stimulus's probability of use is assigned.
- *Certification:* Once verification, inspection and use testing have been completed (and all errors are corrected), the increment is certified as ready for integration.

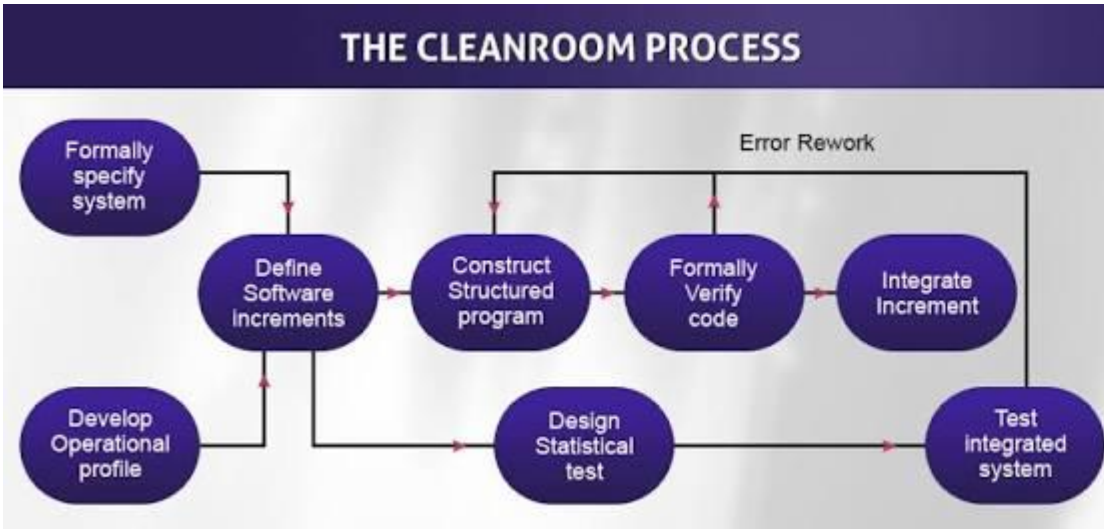

Figure 1: The Cleanroom Process (Source: Pressman, 2005)

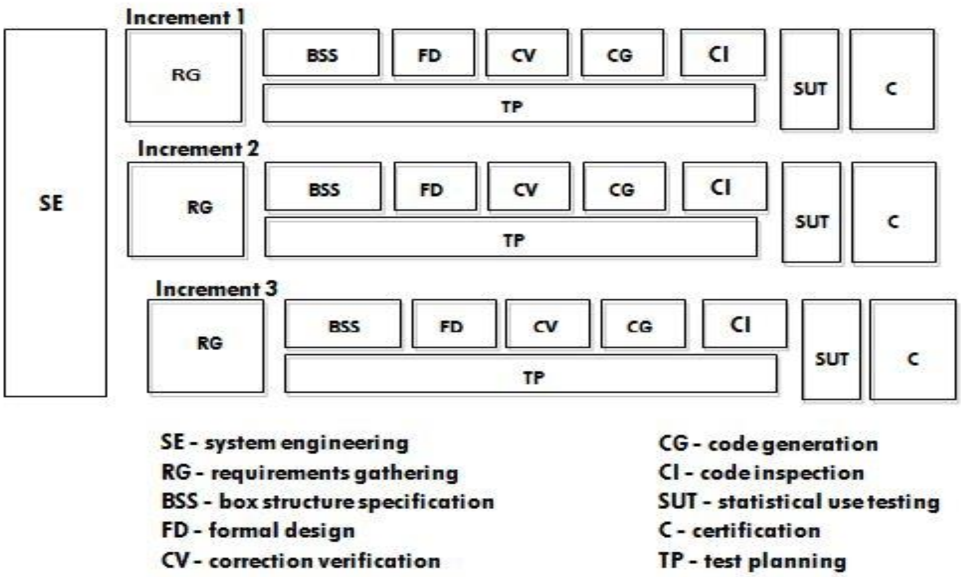

Figure 2: *The Cleanroom Process Model Strategy (Source: Pressman, 2005).*

The nature of the ethnomathematical knowledge covered in the design of the VillageMath Instructional Content Repository calls for a systematic process of assessing and controlling software quality during the development of the platform. The development life cycle of the repository starts with a specification that not only defines function and performance requirements, but also identifies the operational usage of the product and a nested sequence of user function subsets that can be developed and tested as increments, which accumulate into the final system. Correctness verification by the development team is used to identify and eliminate defects prior to any execution of the Repository.

The platform execution is controlled by an independent certification team that uses statistical testing methods to evaluate the quality of the instructional content repository. Statistical testing results in objective quality certification of the repository at delivery and provides a scientific basis for generalising reliability estimates to the operational environment. In combination with incremental development, this fine-grained measurement process substantially improves the predictability of web-based product development. Considering the sensitivity of the cultural aspects of the project, statistical user testing was severally conducted in consultation with potential users of the web-based system, including pre-service teachers, in-service teachers, mathematics educators, and IT experts. Feedback from these vital stakeholders gleaned from social media forums such as Facebook, Nairaland, WhatsApp, and Twitter, as well as usage scenarios created in collaboration with other ethnomathematics enthusiasts, were used to refine all increments of the final system. Such refinements result in remodeling of menu items, disambiguation of associated web-page components, and the installation of helpful plug-ins on VillageMath. For instance, one of the most recent refinements is the addition of BuddyPress to the ngsme.villagemath.net sub-domain.

3. Methodology

This study adopts a developmental research design. This research blueprint is suitable for design-based research, including studies of instructional design and development (Ritchey, Klein & Nelson, 2004). Developmental research is a process that integrates design and scientific methods to allow researchers to generate useful products and effective theories for solving individual and collective problems in education (Easterday, Lewis & Gerber, 2014). Developmental research envisions a tighter, more rigorous connection between learning principles and features of educational innovation. In design research, rigorous analysis of a learning problem by the researcher leads to quite specific ideas for interventions. Designers then build systems that use information technology to create specific teaching and learning materials and methods designed to achieve the learning gains predicted by theory and research (Walker, 2006). Thus, developmental research is the systematic procedure of designing, developing, and evaluating educational interventions, such as programs, teaching-learning strategies and materials, products, and systems, as solutions for complex problems in educational practice. It also aims to advance knowledge about the characteristics of these interventions and the process of designing and developing them (Plomp, 2010). The VillageMath instructional content repository for teachers and learners is a practical educational intervention being developed within the iterative cycles of developmental research design to enhance Science, Technology, Engineering, and Mathematics (STEM) teachers' deployment of indigenous knowledge systems and provide insight into forms of STEM ideas used in diverse contexts and cultural groups.

Data collection for web metrics and key performance indicators (KPIs) will be conducted using WP Statistics Version 14.5.2 (WordPress 6.5.3 with accompanying metric system) and third-party web performance assessment tools such as WebPageTest, Pingdom Tools, Google PageSpeed Insights, and GTmetrix. These four third-party platforms were selected based on their industry reputation, user-friendly interface, and the wide range of KPIs they measure. WebPageTest provides a median performance result that takes into account Time to First Byte (when did the content start downloading?), Start Render (when did pixels start to appear?), Speed Index (how soon did the page look usable?), Cumulative Layout Shift (how much did the design shift while loading?), and Page Weight (how many bytes were downloaded?). Pingdom Tools tests the speed of any website from seven (7) strategically placed locations across five continents around the globe. A typical Pingdom test provides a performance letter grade, load time, and page size. Google PageSpeed Insights indicates a performance score, first contentful paint, first meaningful paint, speed index, and time to interactive. PageSpeed Insights (PSI) evaluates the user experience of a page on both mobile and desktop devices and provides suggestions for improvement. GTmetrix generates a PageSpeed score, fully loaded time, and total page size.

Research question one was answered using values, tables, and charts provided by the Content Managing System (WordPress 6.5.3) adopted by VillageMath. Specifically, common web metrics tracked by WP Statistics 14.5.2 include traffic source, search engine referrals, access device statistics, browser statistics, and hit statistics. Hit statistics account for the number of visits and unique visitors, with the ratio of the two providing a metric value for the average number of pages a visitor views on the villagemath.net platform. In WordPress, the period during which requests from the same uniquely identified client are considered a unique visit is 1800 seconds.

Research question two was answered using values, tables, and charts provided by third-party website performance measuring services such as WebPageTest, Pingdom Tools, Google PageSpeed Insights, and GTmetrix. The key performance indicators (KPIs) that are of utmost importance to this study are load time (speed or response time) and size. Speed Index is a page load performance metric that demonstrates how quickly the contents of a page are visibly populated. The lower the score, the better. Similarly, size refers to the overall weight in megabytes (MB) of the contents of a website. The lower the size, the better. Currently, based on industry standards, the average time it takes to fully load a webpage is 10.3 seconds on desktop and 27.3 seconds on mobile, although recommended targets are 2.5 seconds on desktop and 8.6 seconds on mobile (Dean, 2019; Ryan, 2023; and Ellis & Brandl, 2024). The industry standard page size is 1.88 MB, but 500 KB is recommended (MachMetrics, 2018). Other KPIs measured are first contentful paint, time to interactive, first meaningful paint, and last painted hero. First contentful paint marks the time at which the first text or image is painted. Time to interactive is the amount of time it takes for the web page to become fully interactive. First meaningful paint measures when the primary content of a page is visible. The last painted hero indicates the time it takes for the last important element on the page to be loaded.

4. Presentation of Results

The results of this study are presented according to the research questions.

4.1 Research question one

What is the system specification of the VillageMath instructional content repository?

4.1.1 System specifications

VillageMath Instructional Content Repository is hosted on the Internet under the domain name VillageMath.net, with the full URL being https://villagemath.net. VillageMath runs on a Linux OS server running cPanel Version 120.0 (Build 9). The Repository runs on Apache Version 2.4.59, PHP Version 8.1.28, and MySQL Version 8.0.37.

The VillageMath Repository is managed through WordPress (WordPress Version 6.5.3). WordPress (WordPress.org) is a free and open-source content management system (CMS) based on PHP & MySQL. PHP is a server-side scripting language for creating dynamic web pages. When a visitor opens a page built in PHP, the server processes the PHP commands and then sends the results to the visitor's browser. MySQL is an open-source relational database management system (RDBMS) that uses *Structured Query Language (SQL)*, the most popular language for adding, accessing, and processing data in a database. MySQL is a big filing cabinet where all the content on a site is stored.

As depicted in Figure 3, each time visitors go to https://villagemath.net to interact with the culture-based instructional content, they make a request that is sent to a host server. The PHP programming language receives that request, makes a call to the MySQL database, obtains the requested information from the database, and then presents the requested information to the visitors through their web browsers.

The core features of WordPress include a plugin architecture and a template system. It is most associated with blogging but supports other types of web content, including more traditional mailing lists and forums, media galleries, and online stores. The choice of WordPress 6.5.3 is based on its flexibility, ease of use, outstanding performance statistics as the most popular website content management system, and its use by 60 million websites, including 34% of the top 10 million websites (Colao, 2012; Leibowitz, 2015; BuiltWith, 2019; and W3Tech, 2019).

WordPress is installed on a web server, either as part of an Internet hosting service like WordPress.com or as a computer running the software package WordPress.org to serve as a network host. A local computer may be used for single-user testing and learning purposes. WordPress has a web template system using a template processor. Its architecture is a front controller, routing all requests for non-static URLs to a single PHP file which parses the URL and identifies the target page (Hayes, 2014). This allows support for more human-readable permalinks.

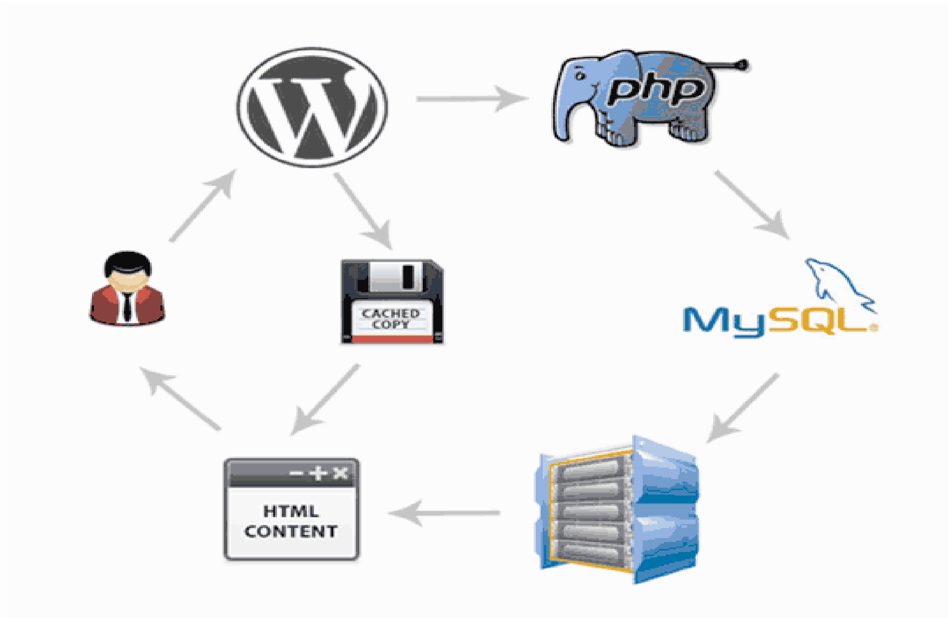

Figure 3: *User Request Pathway in WordPress*

Platforms powered by WordPress may install and switch between different themes. Themes allow users to change the appearance and functionality of a WordPress website without modifying the core code or site content (WordPress, 2019). Every WordPress website needs at least one theme, and each theme should be designed in accordance with WordPress standards, using structured PHP, valid HTML (HyperText Markup Language), and Cascading Style Sheets (CSS). Themes can be installed directly using the "Appearance" administration tool in the WordPress dashboard, or theme folders can be copied directly into the themes directory, for example, via FTP. The PHP, HTML, and CSS found in themes can be directly modified to change theme behaviour, or a theme can be a "child" theme that inherits settings from another theme and selectively overrides features. VillageMath uses the Kontrast theme, designed by ALX Media, while the sub-domain Network for Grassroots Science Mathematics Education (ngsme.villagemath.net) uses the Blossom PinIt theme developed by Blossom Themes.

VillageMath's plugin architecture allows backend administrators to expand the features and functionality of the platform. Each plugin offers custom functions and features that allow users to customise the platform according to their specific needs. These customisations range from search engine optimisation to client portals used to display private information to logged-in users, as well as content management systems and content display features such as widgets and navigation bars.

WordPress also includes integrated link management, a search engine-friendly permalink structure, the ability to assign multiple categories to posts, and support for tagging posts. It also includes automatic filters that provide standardised formatting and styling of text in posts. WordPress also supports the Trackback and Pingback standards for displaying links to other sites that have linked to a post or article. WordPress posts can be edited in HTML using the visual editor or using one of several plugins that offer a variety of customised editing features.

4.2 Research question two

What are the statistics of common web metrics of the VillageMath instructional content repository?

All statistics presented here are from a one-year (5 June 2023 – 5 June 2024) aggregation by WP Statistics.

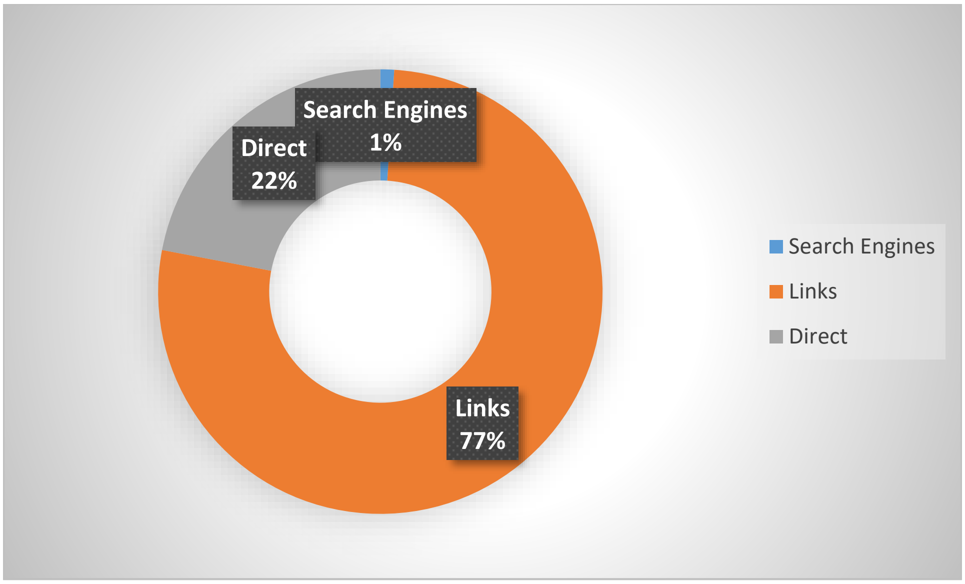

Figure 4: *Traffic Source*

The pie chart in Figure 4 shows traffic sources to VillageMath, including links, direct visits, and search engine leads. A significant portion (77%) of the traffic to the webtool came via links shared on various research and social media platforms. This is followed by traffic that arrived through direct visits (22%) by users typing the platform's URL into their web browsers. Search engines account for only 1% of the traffic, which is a concerning development for the platform.

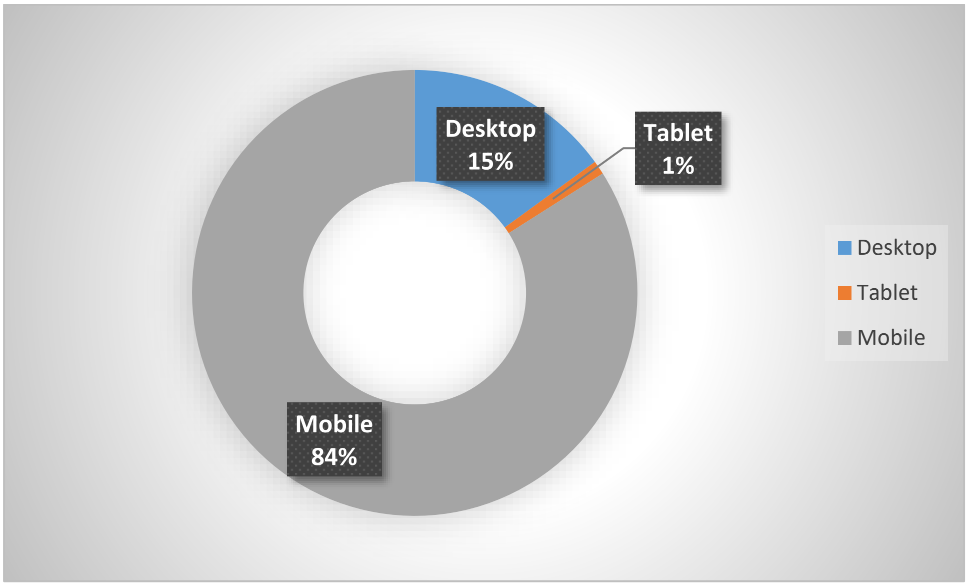

Figure 5: *Devices*

The pie chart in Figure 5 shows that 84% of visitors to the VillageMath Instructional Content Repository visit via mobile devices, particularly smartphones. This is followed by desktop users (15%) using personal computers and laptops. Tablet users account for only 1% of traffic to the platform.

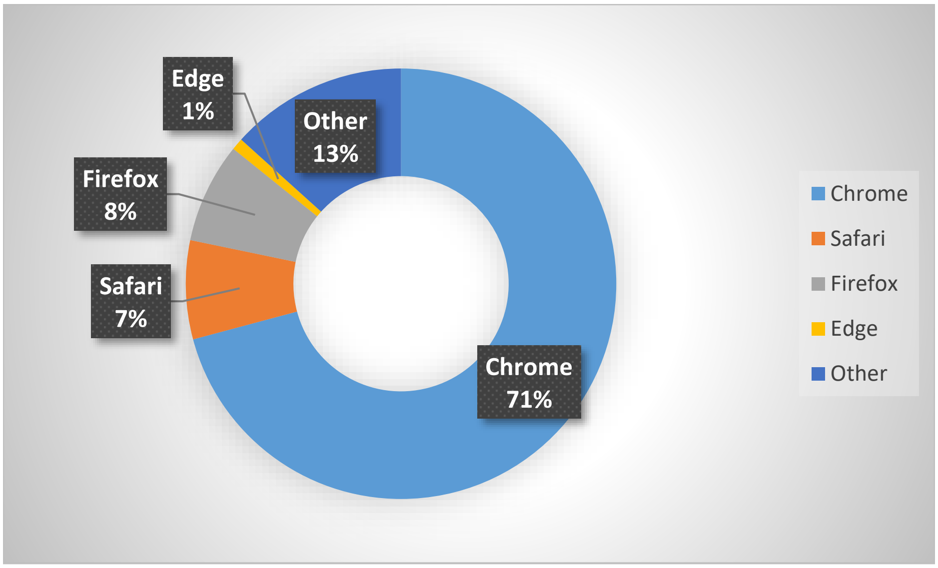

Figure 6: *Browser Statistics*

The data presented in the pie chart in Figure 6 shows that Chrome is the web browser most widely used by users (71%) to visit the VillageMath Instructional Content Repository. The browser statistics indicate that Firefox (8%), Safari (7%), and Edge (1%) had a small share as browsers used to access the VillageMath Intervention. Other less popular browsers account for 13% of the overall access.

Table 1: *One-Year Hits Statistics*

Time	Visits (Views)	Visitors	APPV*
Today (5 June, 2024)	15	11	1.36
Yesterday	12	11	1.09
Last week	115	71	1.62
Last 7 days	194	151	1.28
Last 30 days	4,397	2,339	1.87
Last 60 days	4,541	2,446	1.86
Last 90 days	4,636	2,507	1.85
Last 12 months (5 June 2023 – 5 June 2024)	11,482	8,038	1.43

*APPV: Average Pages Per Visitor = Visits ÷ Visitors

The one-year hit statistics in Table 1 indicate that over the course of one year, a total of 8,038 unique users visited the VillageMath Instructional Content Repository for a total of 11,482 unique visits. This translates to an average of 1.43 pages per visitor. The implication of this APPV is that, on average, each visitor (user) to the platform is engaged enough by the content to navigate to more than one different web page, thereby demonstrating a high level of interaction with the Ethnomathematics Instructional Content Repository.

4.3 Research question three

What is the WebPageTest median run performance result of the VillageMath instructional content repository?

Table 2: *Key Performance Indices from WebPage Test*

Test Location	Time to First Byte	Start Render	Speed Index	Page Weight
Virginia, USA (Mobile)	1.662s	0.000s	0.000s	3KB
Virginia, USA (Desktop)	0.340s	0.000s	0.000s	3KB
Mumbai, India (Mobile)	3.320s	0.000s	0.000s	3KB
Toronto, Canada (Desktop)	0.274s	0.000s	0.000s	4KB
Franfurt, Germany (Desktop)	0.686s	2.000s	3.490s	1.95KB
Mean	**1.256s**	**0.4000s**	**0.698s**	**2.99 KB**

The results in Table 2 are the outcomes of WebPage Tests from 5 different test server locations across the globe. The data indicate that the VillageMath Instructional Content Repository yields a mean time to first byte of 1.256 seconds, a mean start render time of 0.4 seconds, a mean speed index of 0.698 seconds, and a mean page weight of 2.99KB. The mean speed index of 0.698 seconds implies that the website opens at a very high speed when measured against the industry standard of 10.3 seconds.

4.4 Research question four

What is the Pingdom Tools performance grade of the VillageMath instructional content repository?

Table 3: *Key Performance Indices from Pingdom Tools*

Test Server Location	Performance Grade	Load Time	Page Size

Asia – Japan – Tokyo	70 (D)	28.67s	2.2MB
Europe – Germany – Frankfurt	70 (D)	2.28s	2.2MB
Europe – United Kingdom – London	70 (D)	2.06s	2.2MB
North America – USA – Washington DC	70 (D)	0.765s	2.2MB
North America – USA – San Francisco	70 (D)	1.17s	2.2MB
Pacific – Australia – Sydney	68 (D)	3.54s	2.2MB
South America – Brazil – Sao Paulo	70 (D)	3.10s	2.2MB
Mean	**69.71 (D)**	**5.94s**	**2.2MB**

Table 3 shows that the VillageMath Instructional Content Repository scores a performance grade of 69.71 (D) with a mean load time of 5.94 seconds and a page size of 2.2MB. When considering the industry standard loading time of 10.3 seconds, VillageMath loads very quickly. The page size of 2.2MB, which is slightly larger than the industry standard page size of 1.88MB, is due to the graphic nature of the resources available on the platform. However, the page size still results in a fair performance score and fast load time due to the high-level optimisation carried out on all graphic content used on the platform. The overall performance grade of 69.71 (D) indicates that VillageMath is in good health.

4.5 Research question five

What is the Google PageSpeed Insight score of the VillageMath instructional content repository?

Table 4: *Key Performance Indices from Google PageSpeed Insights*

Platform (View Type)	First Contenful Paint	Speed Index	Performance Grade	Accessibility Grade	Best Practices Grade	SEO Grade
Mobile	2.6s	5.0s	50%	76%	72%	92%
Desktop	0.6s	1.5s	70%	76%	75%	92%

The outcomes in Table 4 show the KPIs from Google PageSpeed Insights for both mobile and desktop users of VillageMath. For the mobile platform, the repository returns a first contentful paint of 2.6s, indicating that it takes 2.6 seconds for the first text or image to be displayed for a visitor browsing on a smartphone or any mobile device. The speed index for the mobile view is 5.0 seconds. Corresponding KPIs for a visitor browsing on a desktop platform indicate that VillageMath performs better on desktop devices such as PCs and laptops, with a speed index of 0.6 seconds. When compared to the industry standard loading time of 10.3 seconds, the VillageMath Instructional Content Repository loads very quickly on both mobile and desktop platforms. Additionally, the performance, accessibility, best practices, and SEO (search engine optimisation) grades across both mobile and desktop platforms indicate that VillageMath is evolving favourably.

4.6 Research question six

What is the GTmetrix Speed Index of the VillageMath instructional content repository?

Table 5: *Key Performance Indices from GTmetrix*

Test Server Location	First Contentful Paint	Largest Contentful Page	Fully Loaded Time	Total Page Size	Speed Index	Structure Grade	Performance Grade
Hong Kong, China	2.2s	2.4s	5.3s	703KB	2.7s	78%	51% (D)

London, UK	1.1s	1.7s	2.7s	703KB	1.3s	86%	67% (C)
Mumbai, India	2.9s	3.0s	7.2s	703KB	3.4s	76%	40% (E)
San Antonio, Texas, USA	0.786s	2.2s	2.4s	704KB	1.3s	93%	52% (D)
Vancouver, Canada	0.589s	1.1s	1.7s	704KB	0.788s	90%	75% (B)
Sydney, Australia	1.9s	3.0s	5.1s	704KB	2.4s	81%	49% (D)
Mean	**1.58s**	**2.23s**	**4.07s**	**703.5KB**	**1.98s**	**84%**	**55.67% (D)**

The KPIs from GTmetrix shown in Table 5 indicate a mean Speed Index of 55.67% (D), a mean fully loaded time of 4.07s, and a mean total page size of 703.5KB for the VillageMath Instructional Content Repository. The platform's total page size is smaller than the recommended industry standard of 1.88MB, indicating that the content of the repository is lighter and easier to interact with than many average sites. The mean structure grade of 84% represents how well VillageMath is built for optimal performance. For each test server location, GTmetrix generates a test report which includes recommendations for future improvements. Such recommendations include enabling compression, serving scaled images, leveraging browser caching, optimising images, using an efficient content delivery network (CDN), and compressing components. The mean speed index grade of 55.67 (D) represents a fair performance by the VillageMath Instructional Content Repository.

5. Discussion

The details of the system specifications for VillageMath indicate that the instructional content repository deployed state-of-the-art web technology to project culture-based mathematics education resources in a manner that can be accessed from anywhere in the world. The Content Management System (CMS) used by VillageMath is robust. WordPress' robustness makes it immensely popular and used by millions of people all over the world, powering more than 43% of all websites on the Internet and controlling 64.3% of CMS market share (WPbeginner, 2024). The plugin architecture utilised by VillageMath includes modern security features and ensures healthy maintenance of the platform (Stoyanov et al., 2023). The system specifications of VillageMath attest to the feasibility of WordPress in managing culture-based content as attested by Nguyen (2024). The results for Research Question One also affirm the fact that enriched taxonomy is used in WordPress CMS for information search, structuring, and tagging of blog entries (Zenkert & Fathi, 2024).

The outcomes shown in Table 1 indicated an average of 1.43 pages per visitor for VillageMath. This moderate APPV implies that on average, each visitor (user) to the platform is engaged enough by the content to navigate to more than one different web page, thereby having a high level of interaction with the Repository. These users access the instructional platform via browsers like Firefox, Chrome, Safari, and Edge (Figure 6), using largely mobile smartphones (84%), desktop devices (15%) such as PCs and laptops, and tablets (1%) (Figure 3). Similarly, traffic to the VillageMath Instructional Content Repository came through direct visits (22%) by users typing the platform's https://villagemath.net URL in their web browsers and users who followed links (77%) shared on various research and social media platforms, with search engines accounting for only 1% of the traffic (Figure 4). These web metrics attest to the modern trend of Internet usage across the globe, which points to increasing mobile penetration (Bahia & Suardi, 2019; Kemp, 2019; Iji & Abah, 2019). The active engagement revealed by the platform's average pages per visitor gives the designed tool the potential to build a deeper understanding of mathematics content among users (Agbo-Egwu, Abah & Abakpa, 2018; Abah, Anyagh & Age, 2017).

VillageMath's significance is seen in the all-time search engine referrals, with users from all over the globe visiting. It can thus be inferred that interest in ethnomathematics instructional resources is universal (Kanaiaupuni, 2007). As a learning environment grounded in culture-based mathematics, the VillageMath Instructional Content Repository stands to motivate students' interest in learning Mathematics and enhance their initiatives in the classroom (Yao, 2016; Ofoegbu, Fayemiwo, Omisore, & Olarenwaju, 2014; Garmpis, 2011; Kartam & Al-Rashaid, 2002; Jung, Jun & Gruenwald, 2001).

The statistics in Table 3 show the key performance indices (KPIs) of VillageMath based on Pingdom tools. When seen in the light of industry standards, the page size (2.2 MB) and load time (5.94 seconds) translate to a high performance of the repository because of the high-level optimisation carried out on all graphic contents used on the platform. Similar findings in Table 4 from Google PageSpeed Insights for desktop users of the platform indicate that the repository performs at a speed index of 1.5 seconds. When weighed against the industry standard loading time of 10.3 seconds, the platform loads very fast for both mobile and desktop users. The high grades scored by VillageMath for performance, accessibility, best practice, and SEO are testaments to ongoing efforts at optimising the features of the platform (Dean, 2019; Ryan, 2023; and Ellis & Brandl, 2024). The KPIs from GTmetrix presented in Table 5 indicate a mean fully loaded time of 4.07s and a mean total page size of 703KB for the web-based VillageMath Instructional Content Repository, beating the existing industry standard. This implies that the platform is faster, lighter, and easier to interact with than any average site measured on GTmetrix. The structure grade score of 84% points to the potential of the website to be faster using better practices and optimisation principles. In line with accepted guidelines, these KPIs use dynamic numbers to arrive at an in-depth picture of user behavior on the platform, allowing the VillageMath Instructional Content Repository to align goals, identify areas of improvement, test new functionalities, and ultimately make the desired impact on users (Booth & Jansen, 2010). Accordingly, for each test server location, GTmetrix generates a test report which includes recommendations for future improvements. Such recommendations include enabling compression, serving scaled images, leveraging browser caching, optimising images, using an efficient content delivery network (CDN), and compressing components.

These web analytics influence the number of visits, visitors, and visit duration. Sometimes, it could just be a webpage element that the browser has problems loading. As Horton (2019) observes, if the user gets frustrated and leaves because that last element affects functionality and their ability to do anything or even read text, that ultimately affects the site's bounce rate, time on site, and user satisfaction.

6. Conclusion

VillageMath Instructional Content Repository is developed for the grounding of culture-based mathematics instruction and student learning in the values, norms, crafts, beliefs, practices, experiences, and language that derive from existing indigenous knowledge systems. The aim is to aid the mathematics teacher in seamlessly leading students from the world of life to the world of mathematical symbols. The outcomes of this design have sufficiently proved that the instructional platform can provide a real-world interface that will assist students' problem-solving, support exploration of mathematical concepts, teach dynamically linked representation of ideas, and encourage general metacognitive abilities.

This study specifically evaluated the quality of the designed educational intervention and provided a scientific basis for generalising the reliability of the Instructional Content Repository. Considering the prospects of incremental development, the fine-grained measurement process undertaken in this study substantially improved the predictability of the designed web tool. The repository's cognitive aesthetics design, with user interfaces customised to support different instructional approaches based on user styles and preferences, effectively targets influencing end-users' communication behavior and emotionally impacting their gratification expectancy. The mathematics teachers' appreciation of the cognitive aesthetics built around the culture-based content, as seen in the results of this study, should result in focused usage, guided discovery, intrinsic gratification, and enhanced classroom practice. Pre-service and in-service Mathematics teachers are thus expected to creatively transform the learning objects available on the platform, building on available lesson templates to implement multi-faceted culture-based mathematics education in schools..

The outcomes of this study have demonstrated that culture can indeed become an integral part of every aspect of instructional design, making it important to consider social and cultural peculiarities in planning and delivering mathematics instruction. VillageMath thus has the potential to humanise Mathematics for users and provide a reservoir of resources for training students in conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. This study has established that the designed instructional repository is positively situated to mediate the process of constructing knowledge for mathematics teachers, with an emphasis on students' hands-on activities and indigenous funds of knowledge.

7. Declarations

Author Contributions: Conceptualisation (J.A.A. & C.T.W.); Literature review (J.A.A. & C.T.W.); methodology (J.A.A. & C.T.W.); software (J.A.A.); validation (C.T.W..); formal analysis (J.A.A. & C.T.W.); investigation (J.A.A.); data curation (J.A.A.); drafting and preparation (J.A.A. & C.T.W.); review and editing (J.A.A. & C.T.W.); supervision (C.T.W.); project administration (J.A.A.); funding acquisition (N/A). All authors have read and approved the published version of the article.

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