CHAPTER TEN

Conceptual Foundation for Ethnomathematics Instructional Design in Mathematics Teacher Preparation

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Abstract: Preparing mathematics teachers who can deliver the change we are witnessing and meet the needs of the future requires a concerted effort from all stakeholders in the mathematics education ecosystem. Such efforts must take into account the mediating role of culture-based instructional design in addressing the varying needs of indigenous communities, digital technology users, proposals from early adopters, and the expanding range of opportunities provided by new and future digital technologies. Culture-based educational enhancements depend on how well researchers' and designers' interventions satisfy end-users and the educational and interactional effects the designed tools necessitate. On this basis, this chapter presents a conceptual foundation for ethnomathematics instructional design in mathematics education by first elaborating on the concept of ethnomathematics and the framework for realistic mathematics education. This is followed by a focus on the role of ethnomathematics in mathematics teacher preparation, alongside research-based contextual deployments of culture-based mathematics instructional design. The details of digital content management in instructional environments are then considered, followed by a presentation of empirical case studies of instructional design in teacher preparation. The conceptual presentation in this chapter aims to encourage researchers and practitioners in the field of Mathematics Education to explore the full opportunities and benefits of ethnomathematics instructional design.

Keywords: Digital content management, ethnomathematics, global competence, instructional design, mathematics teacher preparation.

1. Introduction

Education is a conscious effort by society to inculcate its existing body of knowledge, values, norms, science and technology into the younger generation to encourage active participation in society. To achieve this objective, society engages the services of educational institutions where children are guided through well-planned structures. Thus, one of the most urgent aims of education is to facilitate social and economic development while exposing learners to the scientific and analytical thinking skills they need to understand global issues, build a sustainable world, and innovate new technologies (Iji, Abah & Anyor, 2017). Present-day education that is desirable fosters global competence.

The term "global competence" is used in educational research to describe a body of knowledge about world regions, cultures, and global issues, along with the skills and dispositions necessary to engage responsibly and effectively in a global environment (Longview Foundation, 2008). A globally competent student possesses knowledge of and curiosity about the world's history, geography, cultures, environmental and economic systems, and current international issues. Such a student has the language and cross-cultural skills needed to communicate effectively with people from other countries, understand multiple perspectives, and utilise primary sources from around the globe. A globally competent student is committed to ethical citizenship and cultural awareness.

To help students become globally competent, it is essential that teachers possess the knowledge, skills, and dispositions expected of their students. In addition to these capacities, globally competent teachers must understand the international dimensions of their subject matter and a range of global issues; possess pedagogical skills to teach their students to analyse primary sources from around the world, appreciate multiple viewpoints, and recognise stereotyping; and show a commitment to assisting students in becoming responsible citizens of both the world and their communities (Longview Foundation, 2008). Given the era in which we live, digital technology appears to be the fulcrum on which progress in knowledge rests.

Present levels of digital penetration are evolving as technology advances, making access to and use of Information and Communication Technologies (ICTs) an essential element for participation in society, democracy, and the economy. Furthermore, digital equity is the ultimate outcome of ongoing efforts toward digital inclusion, focusing on actions and investments to eliminate historical, systematic, and structural barriers that perpetuate disadvantage among individuals and communities. Globalisation through digital equity acknowledges the moral obligation to harness ICT to address the needs of disadvantaged individuals, communities, neighbourhoods, community-based organisations, and small businesses (Iji & Abah, 2019). This reality must be factored into any programme of teacher preparation.

Thus, training teachers for the global age requires teacher educators, who are preparing future teachers in higher education institutions, to develop the aforementioned capacities, along with the knowledge, skills, and dispositions necessary for teacher candidates to acquire them (Longview Foundation, 2008). For mathematics teacher educators, these capacities entail a kind of meta-knowledge that encompasses at least some of the knowledge that mathematics teachers require, just as teachers of mathematics need to know more than the foundational knowledge required to help students learn mathematics as a school subject (Beswick & Goos, 2018).

The extensive use of digital technology not only raises the need for skills that complement what computers do but also influences the relevance of science, technology, engineering, and mathematics in our society (Gravemeijer et al., 2017; Mncube & Olawale, 2020). Preparing mathematics teachers who can respond to the changes we are witnessing and meet future needs requires a concerted effort from all stakeholders in the mathematics education ecosystem. This effort must take into account the mediating role of culture-based instructional design in addressing the varying needs of indigenous communities, digital technology users, proposals from early adopters, and the expanding range of opportunities offered by new and emerging digital technologies. Culture-based educational enhancements rely on how effectively researchers' and designers' interventions meet the needs of end users and the educational and interactional effects that the designed tools produce (Nouri, Spikol & Cerratto-Pargman, 2016). The lifecycle, therefore, must consider well-defined collaboration among mathematics teacher educators, mathematics teachers, and designers, particularly during the implementation of the artefact (Iversen & Jonsdottir, 2018).

For digital tools aimed at amplifying the recognition that every cultural group generates its own mathematics, ethnomathematics instructional design must crowdsource primary resources, tested classroom practices, culture-based lesson templates, and other localised content from practising mathematics teachers. This entails context-sensitive design elements drawn from numerous micro-communication processes, resulting in a research-based consequences feedback loop, both positive and negative, expected and unexpected.

This chapter takes a holistic view of the necessity for a sound conceptual foundation for ethnomathematics instructional design in mathematics teacher preparation and the necessary adjustments that can be made to mathematics teacher preparation schemes across different levels. The presentation begins with an overview of ethnomathematics, followed by a consideration of a framework for realistic mathematics education and an exploration of the dimensions of ethnomathematics in contemporary mathematics teacher preparation. The work also examines instances of culture-based instructional design and concludes with a discussion on digital content management in instructional environments, accompanied by case studies from empirical research.

2. Ethnomathematics

One of the most relevant reasons for teaching Mathematics is the consideration of Mathematics as an expression of human development, culture, and thought, highlighting its integral role in the cultural heritage of humankind. Although contemporary society places great value on a Western-oriented approach to science and mathematics, ethnomathematics has demonstrated that mathematics comprises many diverse and distinct cultural traditions, not just those emerging from the Mediterranean basin mathematics tradition (Rosa & Orey, 2010). Mathematical thinking has been influenced by the vast diversity of human characteristics, such as languages, religions, morals, and economic, social, and political activities. In view of these multidimensional influences, humans have developed logical processes related to universal needs to quantify, measure, model, and explain, all operating within different socio-historical contexts (Abah & Chinaka, 2024).

Since each cultural group has its own way of doing Mathematics, the connections often come to represent a given cultural system, particularly in the manner in which they quantify and use numbers, geometric forms and relationships, and measure or classify objects in their own environment. Rosa and Orey (2010) state that for all these reasons, each cultural group has developed its unique way of mathematizing its own realities. In this sense, D'Ambrosio (2001a) defines Ethnomathematics as the Mathematics practiced by cultural groups, such as urban and rural communities, groups of workers, professional classes, children in a group, indigenous societies, and numerous other groups identified by the objectives and traditions common to these groups. In simple terms, ethnomathematics is used to express the relationship between culture and mathematics.

The everyday life of groups, families, tribes, communities, associations, professions, and nations occurs in different regions of the planet, in various ways and at different paces, with the individuals within them sharing knowledge such as language, systems of explanation, myths and legends, customs, and culinary habits. The behaviours of members are made compatible with and subordinated to value systems agreed upon by the group, thereby forming a culture. In sharing knowledge and aligning behaviours, the characteristics of a culture are synthesised (D'Ambrosio, 2001a). Essentially, the distinct way of doing (practice) and knowing (theory) that characterises a culture is part of the shared knowledge and behaviours that have become compatible.

Everyday life is imbued with the knowledge and practices of a culture. At all times, individuals are comparing, classifying, quantifying, measuring, explaining, generalising, inferring, and, in some way, evaluating, using material and intellectual instruments that belong to their culture (D'Ambrosio, 2001a). These individuals are actively employing the arts or techniques of explaining, understanding, and coping with their environments that they have learned in their cultural settings. This inherited knowledge of their cultural group constitutes the ethnomathematics of the group (D'Ambrosio, 1994).

3. The Framework for Realistic Mathematics Education (Freudenthal, 1968)

Realistic Mathematics Education (RME) is a domain-specific instructional framework for mathematics. Essentially, RME emphasises the importance of rich, "realistic" situations in the learning process. These situations serve as a source for initiating the development of mathematical concepts, tools, and procedures, and as a context in which learners can later apply their mathematical knowledge, which gradually becomes more formal and general, and less context-specific. Although "realistic" situations, in the sense of "real-world" contexts, are important in RME, the term "realistic" has a broader connotation here.

The foundation of Realistic Mathematics Education (RME) is credited to Hans Freudenthal (1905–1990), a mathematician born in Germany who became a Professor of Pure and Applied Mathematics and the Foundations of Mathematics at Utrecht University in the Netherlands in 1946. Later in his career, Freudenthal (1968, 1973, 1991) became interested in mathematics education and advocated for teaching mathematics that is relevant for learners, conducting thought experiments to explore how learners can be given opportunities for the guided re-invention of mathematics.

One of the foundational concepts of RME is Freudenthal's idea of mathematics as a human activity. For him, mathematics is not a static body of knowledge but the activity of solving problems and seeking new problems. More broadly, it is the activity of organising elements from reality or mathematical concepts, which he referred to as "mathematization" (Freudenthal, 1968). This activity-based interpretation of mathematics has significant implications for how mathematics education is conceptualised. Specifically, it influences both the goals of mathematics education and the teaching methods employed (Van den Heuvel-Panhuizen, 2003). According to Freudenthal (1968, 1971, 1973), mathematics can best be learned by doing, and mathematization is the core goal of mathematics education. Rather than presenting mathematics as a ready-made product, the objective should be to engage learners in mathematics as an activity. Thus, similar to how the mathematical activities of mathematicians have shaped mathematics as it is known today, the activities of learners should lead to the construction of mathematics, effectively allowing them to invent mathematics (Gravemeijer, 2008).

The tenets of RME distinguish between two ways of mathematizing in an educational context, namely "horizontal" and "vertical" mathematizing. In the case of horizontal mathematizing, mathematical tools are employed to organise and solve problems situated in daily life. Vertical mathematizing, in contrast, refers to various reorganisation and operations undertaken by learners within the mathematical system itself. According to Freudenthal (1991), to mathematize horizontally means to transition from the world of life to the world of symbols, while to mathematize vertically involves movement within the world of symbols. The latter implies, for instance, making shortcuts, discovering connections between concepts and strategies, and utilising these findings (Van den Heuvel Panhuizen, 2003). In RME, emphasis is placed on the notion that both forms of mathematizing hold equal value and can occur at all levels of mathematical activity.

Essentially, ethnomathematics as a programme of mathematics education highlights the importance of providing realistic situations within the instructional process. The design of ethnomathematics instruction serves as a means to project the mathematical concepts and knowledge embedded in learners' real lives and cultural practices. Frequent references to the history of mathematics and storytelling within developed instructional tools present problem situations that learners can envision and relate to as experientially real (Abah, Iji & Abakpa, 2018). The content coverage of digital tools designed on this foundation aims to humanise mathematics for users, guiding them in ways to re-invent Mathematics for themselves.

In terms of mathematization, the educational products developed within the scope of ethnomathematics instructional design are tools that can be creatively utilised to organise and solve problems situated in students' daily lives. This makes the platform an indispensable companion for teachers engaging in horizontal mathematization. For instance, the blog articles, lesson plans, adaptable classroom activities, and ethnomathematics forum provided by a web-based ethnomathematics repository have been shown to assist mathematics teachers in seamlessly transitioning from the world of life to the world of mathematical symbols (Abah, Iji, Abakpa & Anyagh, 2021; Abah, 2024). The engaging activities available on the platform demonstrate that Mathematics is best learned by doing mathematics.By building on the reality principle of Realistic Mathematics Education, Abah, Iji, Abakpa, and Anyagh (2021) and Abah (2024) designed the Ethnomathematics Instructional Content Repository to present resources that encourage mathematics teachers to start from problem situations that are meaningful to students and are derived from the learners' rich cultural contexts. This approach allows students to move from context-related situations to constructing practical mathematical strategies, progressing through a spiral of intertwined curricular content to achieve success. In learning and doing mathematics, technology in the form of real-world interfaces, such as the Ethnomathematics Instructional Content Repository, can assist students with problem-solving, support the exploration of mathematical concepts, provide dynamically linked representations of ideas, and encourage general metacognitive abilities such as planning and checking (Barkatsas, 2004). The adaptable teaching templates available from the repository can aid mathematics teachers in providing the necessary guided re-invention and group discussions that will develop students' conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Kilpatrick & Findell, 2001). Consequently, culture-based digital tools mediate for practising mathematics teachers the process of constructing knowledge, with an emphasis on pupils' hands-on activities and everyday life.

4. Ethnomathematics in Mathematics Teacher Preparation

Ethnomathematics requires a dynamic interpretation because it describes concepts that are neither rigid nor singular, namely "ethno" and "mathematics" (D'Ambrosio, 1987). The term "ethno" encompasses all the elements that constitute the cultural identity of a group: language, codes, values, jargon, beliefs, food, dress, habits, and physical traits. Mathematics expresses a broad view of itself, which includes ciphering, arithmetic, classifying, ordering, inferring, and modelling (D'Ambrosio, 1987). Many educators may be unfamiliar with the term; however, a basic understanding of it allows teachers to expand their mathematical perceptions and instruct their students more effectively.

Teachers, and the public in general, do not commonly acknowledge the connection between mathematics and culture (D'Ambrosio, 2001b). When teachers do recognise a connection, they often engage their students in multicultural activities merely as a curiosity. Such activities typically refer to a culture's past and to cultures that are very remote from those of the children in the class. This situation arises because teachers may not understand how culture relates to children and their learning. An important component of mathematics teacher preparation today should be to reaffirm, and in some instances restore, the cultural dignity of children (D'Ambrosio, 2001b). Although multicultural mathematics activities are important, they should not be our ultimate goal. As students engage in multicultural mathematical activities that reflect the knowledge and behaviours of people from diverse cultural environments, they may not only learn to value mathematics but, just as importantly, develop a greater respect for those who are different from themselves.

To acquire requisite skills while maintaining cultural dignity and be prepared for full participation in society requires more than what is offered in a traditional curriculum. Much of today's curriculum is so disconnected from the child's reality that it is impossible for the child to be a full participant in it (D'Ambrosio, 2001b). The mathematics taught in many classrooms has practically nothing to do with the world that the children are experiencing. Just as literacy has come to mean much more than reading and writing, mathematics must also be considered as more than, and indeed different from, counting, calculating, sorting, or comparing. Considering that today's children live in a civilisation dominated by mathematically based technology and unprecedented means of communication, it is safe to assert that much of the content of current mathematics programmes does little to help students learn the information and skills necessary to function successfully in this new world.

The goal of Mathematics Education should be to foster students' ability to successfully use modern technology to solve problems and communicate their thinking and answers while gaining an awareness of the capabilities and limitations of technological instruments. The school system can help learners realise their full mathematical potential by acknowledging the importance of culture to the identity of the child and how culture affects the way children think and learn. Children must be taught to value diversity in the mathematics classroom and to understand both the influence that culture has on Mathematics and how this influence results in different ways in which mathematics is used and communicated (D'Ambrosio, 2001b). Such understanding is gained through the study of ethnomathematics.

As a programme, ethnomathematics studies the cultural aspects of Mathematics. It acknowledges that there are different ways of doing Mathematics by considering the appropriation of academic mathematical knowledge developed by various sectors of society, as well as the different modes in which various cultures negotiate their mathematical practices. Ethnomathematics researchers investigate how different cultural groups comprehend, articulate, and apply ideas, procedures, and techniques identified as mathematical practices (Rosa & Shirley, 2016). These mathematical practices refer to forms of Mathematics that vary as they are embedded in cultural activities. Ethnomathematics presents the mathematical concepts of the school curriculum in a way that relates these concepts to the cultural backgrounds of students, thereby enhancing their ability to make meaningful connections and deepening their understanding of Mathematics.

Development within the field of ethnomathematics represents a methodology for ongoing research and analysis of the processes that transmit, diffuse, and institutionalise mathematical knowledge, ideas, processes, and practices that originate from diverse cultural contexts throughout history. This context has enabled the development of six important dimensions of ethnomathematics, which are interrelated and aim to analyse the socio-cultural roots of mathematical knowledge. Rosa and Shirley (2016) summarise the six dimensions as follows:

- *Cognitive:* This dimension concerns the acquisition and dissemination of mathematical knowledge across generations. Mathematical ideas such as comparison, classification, quantification, measurement, explanation, generalisation, modelling, and evaluation are understood as social, cultural, and anthropological phenomena that trigger the development of knowledge systems elaborated by members of distinct cultural groups. In this regard, it is not possible to evaluate the development of cognitive abilities apart from social, cultural, economic, environmental, and political contexts.
- *Conceptual:* The challenges of everyday life provide members of distinct cultural groups with the opportunity to answer existential questions by creating procedures, practices, methods, and theories based on their representations of reality. These actions constitute a fundamental basis for the development of essential knowledge and decision-making processes. Survival depends on immediate behaviour in response to routines inherent to the development of group members. Thus, mathematical knowledge emerges as an immediate response to the needs for survival and transcendence.
- *Educational:* This dimension does not reject knowledge and behaviour acquired academically, but incorporates human values such as respect, tolerance, acceptance, caring, dignity, integrity, and peace into the teaching and learning of Mathematics to humanise it and bring it to life. In this context, ethnomathematics promotes the strengthening of academic knowledge when students understand the mathematical ideas, procedures, and practices present in their daily lives. These are the main ideas of "nonkilling mathematics" as proposed by D'Ambroiso in his search for peace and transcendence.
- *Epistemological:* This dimension deals with knowledge systems, which are sets of empirical observations developed to understand, comprehend, explain, and cope with reality. Thus, three questions arise regarding the evolution of mathematical knowledge in relation to diverse forms of generation, organisation, and dissemination: (a) how to move from ad hoc observations and practices to experimentation and methods; (b) how to move from experimentation and method to reflection and abstraction; and (c) how to proceed towards inventions and theories. These questions guide reflections regarding this evolution by considering the unique interplay between people and their own reality.
- *Historical:* It is necessary to study the links between the history of mathematics and the reality of the learners. This dimension leads students to examine the nature of Mathematics in terms of understanding how mathematical knowledge is allocated in their individual and collective experiences. Thus, knowledge is constructed from the interpretations of how humanity has analysed and explained mathematical phenomena throughout history. This is why it is necessary to teach mathematics within a historical context, so students can understand the evolution of and the contributions made by other peoples to the ongoing development of mathematical knowledge
- *Political:* This dimension aims to recognise and respect the history, tradition, and mathematical thinking developed by members of distinct cultural groups. It stresses the

importance of recognising and respecting the socio-cultural roots of others while reinforcing these roots through dialogue in cultural dynamism. It also aims to develop political actions that guide students in transitioning from subordination to autonomy, helping them to gain a broader understanding of their rights as citizens.

These dimensions show that the ethnomathematics programme has an agenda that offers a broader view of mathematics that embraces ideas, processes, methods, and practices that are related to different cultural environments. This aspect leads to increased evidence of cognitive processes, learning capabilities, and attitudes that may direct the learning process occurring in our classrooms. Ethnomathematics offers an important perspective for a dynamic and globalised modern society that recognises that all cultures and all people develop unique methods and explanations that allow them to understand, act, and transform their own reality. The need to imbibe this perspective in present-day mathematics instructional design cannot be overemphasised.

5. Culture-based Mathematics Instructional Design

Culture is a learned behaviour consisting of thoughts, feelings and actions and is transferred in social interaction (Vanio, Walsh & Varsaluoma, 2014). Within every culture, there exists 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 et al., 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 and other digitally designed tools (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 artefact 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 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, 2009). Cross-cultural design is designing technology for different cultures, languages, and economic standings, ensuring usability and user experience across cultural boundaries (Vanio, Walsh & Varsaluoma, 2014). Such a user-centred design approach supports the cross-cultural product development process with user-centred activities identifying the need for internationalisation and localisation.

In the field of instructional technology, "development" has a somewhat unique connotation. A typical 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: artefacts 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 artefacts, and practice.

Basically, design-based research (DBR) 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 in education (Easterday, Lewis & Gerber, 2014). Ethnomathematics instructional design, like other DBR processes, consists 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 programme that calls upon curriculum planners and implementers to incorporate indigenous knowledge systems within Mathematics. The extent to which mathematical knowledge is exhibited in cultural villages, both by the workers and in the artefacts made, was discussed in relation to how these can be used in mathematics classrooms. Mosimege (2004) lists mathematical concepts identified in the making of a grass container and 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 standardized test scores (Best & Dunlap, 2013). Fenyvesi, Koskimaa, and Lavicza (2014) show that creating visual illusions, paradox structures, and "impossible" figures through playful and artistic procedures holds an exciting pedagogical opportunity for raising students' interest in mathematics. To anchor this, innovatively designed games were deployed to clarify mathematical concepts 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 Programme on the islands of Haida Gwaii were interviewed to determine how they "Do the Math" in their daily lives. The programme "consists of elders, professionals and community members who 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 that mathematics is useful and meaningful for the Indigenous students is demonstrated by showing them how traditional and contemporary cultural activities have many mathematical concepts embedded in them. Neel (2010) reports that broadly, the 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 gourds, with the outcome affirming that out-of-school practices are dynamic in nature and they are performed along an informal-formal learning continuum.

6. Digital Content Management in Instructional Environments

Today's learners have changed incrementally from those of the past due to the arrival and rapid dissemination of digital technology. Connected devices, social networks, educational cloud services and other innovations have essentially inverted relationships between learners and schools (Elliot, Kay & Laplante, 2016; Iji, Abah & Anyor, 2017; Iji, Abah & Anyor, 2018).

Today's learners represent the first generations to grow up with this new technology, spending their entire lives surrounded by and using computers, video games, digital music players, video cameras, smartphones and all other toys and tools of the digital age (Prensky, 2001). Learners today are native speakers of the digital language of computers, video games and the Internet.

These disruptive technological changes imply that teachers have to learn to communicate in the language and style of their students. There is also an enforced redefinition of instructional content. In this sense, Prensky (2001) observes that there are now two kinds of content: "Legacy" content and "Future" content. Legacy content includes reading, writing, arithmetic, logical thinking, and understanding the writings and ideas of the past and the traditional curriculum. Future content is to a large extent digital and technological. Evidently, present-day educators need to think about how to teach both legacy and future content in the language of the Digital Natives (Prensky, 2001).

Digital content is referred to by one or more several terms including reusable learning objects, electronic records, digital assets, datasets and media assets. Basically, the term digital content is a general one that encompasses text, image, audio and multimedia digital files, and datasets that are used for the purposes of instruction, research and study (Cywin *et al.*, 2011). These digital files are referred to as assets because a significant amount of time, effort and expenses goes into creating content, thus making the files a valuable resource. However, the value of these assets can only be truly realised if they are accessible to everyone who needs them, when they need them (Extensis, 2018). Digital materials provide many teaching and learning benefits to educators and students. They can be updated more quickly than traditional print materials, may be adapted to address students' learning differences and styles, and can offer interactive functions that pique learners' interests (State Educational Technology Directors Association - SETDA, 2015). These advantages are particularly true of digital Open Educational Resources (OER), which offer a lawful pathway for tailoring and adapting content to meet a student's unique learning needs.

Digital Content Management (DCM) has been defined as a series of tasks and decisions surrounding the annotation, cataloguing, storage, retrieval, and distribution of digital content (Cywin *et al.*, 2011). However, in light of recent technological developments, the phrase "Digital Content Management" has become more synonymous with software applications and enterprise solutions. A digital content management system is built upon a central repository that facilitates digital file storage, organisation, retrieval, utilisation, and reuse. Such a system is a "filing cabinet" containing individual files that are stored with detailed information or metadata about a digital asset (Frey, Williams-Allen, Vogl & Chandra, 2005). Metadata can be wrapped around information as a sort of digital data container. The data container is a set of categories, such as creation date, creator, additional versions, related files, and copyrights (Frey *et al.*, 2005). Digital Content Management Systems tend to be very robust and address a many-to-many relationship with database objects, particularly within systems designed to aid mathematics instruction.

The Web-based Ethnomathematics Instructional Content Repository reported by Abah, Iji, Abakpa, and Anyagh (2021) and Abah (2024) is managed through WordPress. WordPress (WordPress.org) is a free and open-source content management system (CMS) based on PHP and 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. Every time visitors go to https://villagemath.net to interact with ethnomathematics instructional content, they make a request that is sent to a host server (Abah, Iji, Abakpa, & Anyagh, 2021; Abah, 2024). 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 (See Figure 1).

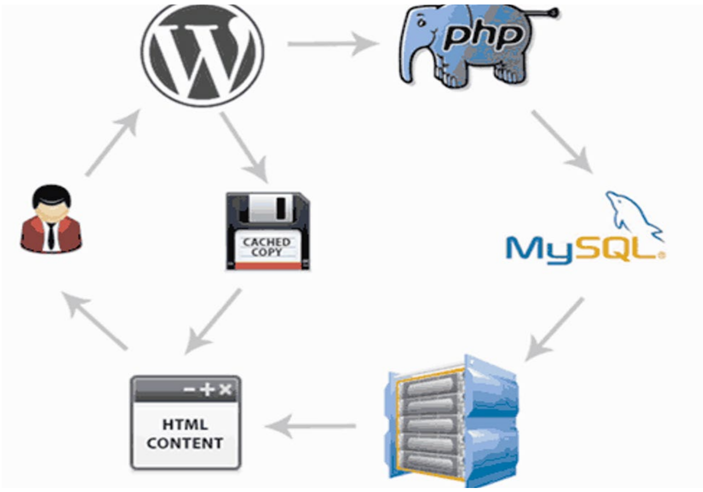

Figure 1: *User Pathway in WordPress*

Digital Content Management Systems are integrated processes, which can be broken down into three parts by function (Frey *et al*.., 2005):

i. *Collection:* During collection, raw information is transformed into a set of content components. Information is created or acquired, converted into a master format (e.g. XML) if necessary, edited, segmented into components, and has metadata added.

ii. *Management:* The management function is part of the administrative infrastructure of a DCM System. In general, the administrative infrastructure provides a way to keep track of digital assets and associated status. It is a repository used for long-term storage and other administrative resources. The repository is made up of database records and/or files that hold content and other administrative data (such as a system's users).

iii. *Publishing:* The publishing function can combine content components and other resources from the repository to create publications. Publications can be created in a variety of formats, printable or electronic (e.g. web, e-mail). They consist of components, functionality, metadata, and navigation information. Content can also be published simultaneously in multiple formats.

With the robustness of digital content management, delivering experiences – rather than merely publishing content – is an aspirational goal for educational initiatives. Elliot, Kay, and Laplante (2006) state that the availability of proven technologies for content and experience management is not a key challenge, as the technology landscape is mature and populated with choices that meet most intervention needs, with some categories offering digital capabilities well beyond web publishing. In relation to culture-based content, such systems aim to preserve cultural heritage and collections; popularise fine cultural landmarks; encourage information and knowledge sharing; invigorate cultural content and value-added services; and improve literacy, creativity, and quality of life (Hsu, Ke, & Yang, 2006). A knowledge management framework not only aims to manage knowledge assets but also to manage the processes that act upon the assets. These processes include developing, preserving, using, and sharing knowledge, as shown in the system framework in Figure 2.

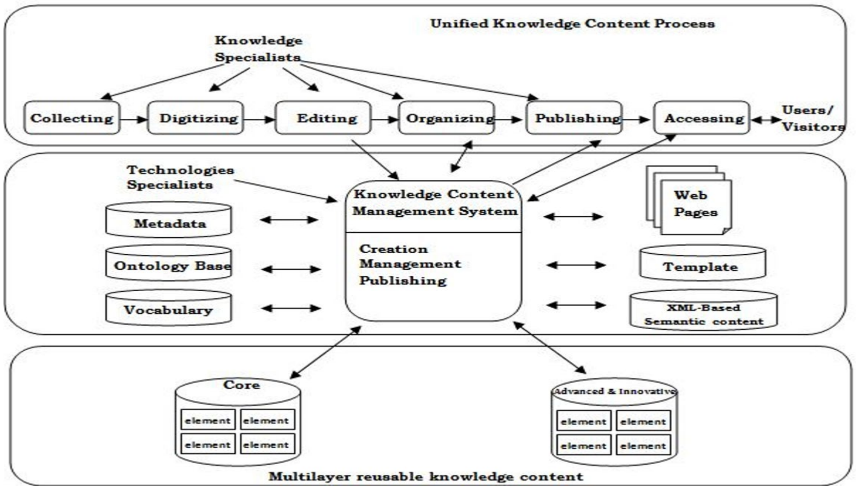

Figure 2: *Unified Knowledge-based Content Management System Framework* (Source: Hsu, Ke & Yang, 2006)

The three components of this framework are unified content processes, an integrated knowledge-based content management system, and a multilayer reusable knowledge content structure. The first component functions as a common workflow among participants and projects that include knowledge content collection, digitisation, editing, organising, publishing, and accessing stages (Hsu, Ke & Yang, 2006). The multilayer reusable knowledge content structures define the spectrum of knowledge content for all participants to follow, from core knowledge elements to advanced and innovative elements. A core knowledge element is the basis of knowledge content and comprises a multimedia object and semantic metadata. Advanced and innovative elements are further manually authored or automatically inferred from existing content. The integrated knowledge-based content management system comprises the creation subsystem for constructing vocabulary, metadata, content, and the classification hierarchy, the management subsystem, and the publishing subsystem to transfer the authored content into the publishing structure and web pages for all users (Hsu, Ke & Yang, 2006).

In an instructional environment, Ghirardini (2011) relates that e-learning approaches can combine four (4) broad types of e-learning components.

i. E-Learning content

E-learning content can include simple learning resources, interactive e-lessons, electronic simulations, and job aids. Simple learning resources are non-interactive resources such as documents (Word and PDF), PowerPoint presentations, videos, or audio files. These materials are non-interactive in the sense that learners can only read or watch content without performing any other action. These resources can be quickly developed and, when they match defined learning objectives and are designed in a structural way, they can be a valuable learning resource even though they do not provide any interactivity.

The most common approach for self-paced e-learning is web-based training consisting of a set of interactive e-lessons. An e-lesson is a linear sequence of screens that can include text, graphics, animations, audio, video, and interactivity in the form of questions and feedback. E-lessons can also include recommended reading and links to online resources, as well as additional information on specific topics.

Simulations are also highly interactive forms of e-learning. The term "simulation" basically means creating a learning environment that mimics the real world, allowing the learner to learn by doing. Simulations are a specific form of web-based training that immerse the learner in a real-world situation and respond in a dynamic way to their behaviour.

Job aids provide just-in-time knowledge. They usually provide immediate answers to specific questions, thus helping users to accomplish job tasks. Technical glossaries and checklists are a few examples of simple job aids, but they can also assist workers in complex decision-making.

ii. E-tutoring, e-coaching, e-mentoring

These services add human and social dimensions to learners, supporting them throughout the learning experience. E-tutoring, e-coaching, and e-mentoring offer individual support and feedback to learners using online tools and facilitation techniques.

iii. Collaborative learning

Collaborative activities encompass discussions and knowledge sharing, as well as working together on a common project. Social software, such as chats, discussion forums, and blogs, is utilised for online collaboration among learners. Synchronous and asynchronous online discussions allow learners to comment and exchange ideas about course activities, as well as contribute to group learning by sharing their knowledge. Collaborative project work entails cooperation among learners to complete a task. Collaborative activities may include project work and scenario-based assignments.

iv. Virtual classroom

A virtual classroom is the instructional method most similar to traditional classroom training, as it is entirely led by an instructor. It is an e-learning event where an instructor teaches remotely and in real time to a group of learners using a combination of materials, such as PowerPoint slides and audio or video content. This format is also referred to as synchronous learning.

7. Empirical Case Studies

The conceptual frameworks for instructional design presented thus far have been practically deployed in various studies under different conditions for a wide range of teacher preparation purposes. Wang, Zhou, and Zou (2004) conducted a study on the Web-based Mathematics Education Framework (WME), which aims to create a web for mathematics education, empowering mathematics teachers, learning content developers, and dynamic mathematics computation and education service providers to deliver an unprecedented mathematics learning environment to students and educators. WME provides an authoring language—Mathematics Education Markup Language (MeML)—which works with regular browsers, simplifies page creation, allows systematic access to supporting WME services, and enables independently developed components to interoperate seamlessly. The designed MeML aims to provide an effective and expressive means for authoring and delivering both static and dynamic content on the web. The MeML Document Type Definition (DTD) defines the syntax of MeML elements. The prototype client-side WME Page Processor, Woodpecker, includes an XSLT processor, XSLT templates, and a collection of web browser plug-ins called MeML plug-ins. Translation is performed by an XSLT processor. The translated XHTML page may also include embedded event handlers (in Javascript) and references to MeML plug-ins. The WME/MeML represents an ambitious vision that, when fully realised, will revolutionise computing in mathematics education, making the presentation of mathematical symbols, equations, styles, and fonts easy on the web.

In a related study, Changiz, Haghani, and Masoomi (2012) provided a report on the design and implementation of a web directory for medical education, creating a tool to facilitate research in this field. The objective was to design and implement a comprehensive, subject-specific web directory to ease access to medical resources online. The categories to be included in the directory were defined through a review of related directories and consultations with medical education experts in a focus group. Sources such as search engines, subject directories, databases, and library catalogues were searched to select and collect high-quality resources. The main categories indexed are journals, organisations, best evidence, and textbooks. Sub-categories and related resources for each category are described and linked. Despite the success of the implemented directory, limitations related to the inherent constraints of subject directories were reported. The database size of subject directories is very small compared to search engines, indexed sites and resources in subject directories are typically updated with delays, there is a risk of overlooking potentially useful sites and resources, and the costs of maintenance and updating are high.

In a study implementing a game to support learning in mathematics, Katmada, Mavridis, and Tsiatsos (2014) focused on the design, implementation, and evaluation of an online game for elementary and middle school mathematics. The two-fold aim of the effort was the development of a prototype for a flexible and adaptable computer game, and the evaluation of this prototype regarding its usability and technical aspects. In addition to the game, an administration website was constructed to enable educators to configure the game by altering various parameters, such as the content and total number of questions. The game was evaluated in real school settings through a pilot study involving 12 students, followed by a long-term intervention with 37 students lasting 14 weeks. The results indicated that students had a positive opinion of the game and suggested that, with some enhancements, it could serve as an effective learning tool. Although the study suggests that game-based learning activities were well accepted and appreciated by the students, some encountered minor usability challenges. Specifically, "five students stated in their comments that they would prefer the game to be in Greek rather than English" (p.238), indicating a missing ethnomathematical dimension.

A Nigerian study by Charles and Babatunde (2014) presented the design and implementation of a virtual classroom system focused on collaborative learning between students and tutors at remote locations. The various components of the system allow students to engage in group activities and collaborate with instructors in commonly shared windows where text, audio, or video objects can be added and shared online. The system was developed and hosted on the web using Moodle, Elluminate, WAMP server, JavaScript, MySQL, PHP, and Dreamweaver. A practical demonstration was conducted using an undergraduate course in the Department of Computer Science at the Federal University of Technology, Akure, Nigeria. Results from the demonstration exhibited the suitability and adequacy of the virtual classroom system. The views and responses of 100 students and 10 instructors from FUTA were gathered through a questionnaire featuring indices such as accessibility, provision of an appropriate level of interaction, efficiency of support for learning methods, convenience of use, usefulness for active learning, and aid to teaching. These indices broadly align with the criteria for evaluating the quality of web-based instructional environments.

The study by Abah, Iji, Abakpa, and Anyagh (2021) adopted a developmental research design to systematically build and evaluate an educational intervention as a solution to complex problems in mathematics education practice. This development was achieved using WordPress Version 5.4, hosted online at https://villagemath.net on a Linux OS server running cPanel v80.p (Build 20), Apache Version 2.4.39, PHP Version 5.6.40, and MySQL Version 5.7.26. The study examined common web metrics, key performance indices, and quality assessment in terms of content, navigation, structure, appearance, and uniqueness of the designed web tool. The results yielded a positive pattern of common web metrics for the designed web tool, indicating that the platform appeals to a wide range of users. Key performance indicators such as speed index, page size, and last painted hero affirmed that the platform is robust, elegantly designed, and fast. The outcomes from Abah, Iji, Abakpa, and Anyagh (2021) 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. The Web-based Ethnomathematics Instructional Content Repository has humanised mathematics for users and provided a reservoir of resources for training students in conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition.

The context of presenting a culture-based mathematics education repository is expected to be structured in culturally appropriate ways, making learning meaningful and relevant through culturally grounded content and assessment. The system must also gather and maintain data to ensure progress in culturally responsible ways. On these premises, Abah (2024) undertakes a re-examination of an earlier designed web tool to present the outcomes of the structural quality assessment of the VillageMath educational intervention for mathematics teachers. The analysis of the results affirmed the structural quality of VillageMath, indicating that mathematics teacher educators in institutions of higher learning can continue to use the platform as a dependable tool for voicing narratives across the field of ethnomathematics. The forum available on the platform can be utilised by these experts in mathematics education to communicate their development of state-of-the-art pedagogies for the field, particularly in extending narratives of African indigenous knowledge systems.

8. Conclusion

The deliberations of this chapter have highlighted the existing gap in the literature regarding the incorporation of cultural competence and diversity training in teacher preparation programmes. The review has adequately showcased the potential of culture-based mathematics instructional design in integrating culturally responsive teaching practices, addressing implicit biases, and promoting equity and social justice in mathematics education. The diverse case studies cited in the discussion underscore growing efforts in the instructional design community to project the cultural significance of mathematical abstractions as they emerge and are used in the everyday lives of learners. Teacher preparation programmes in higher education institutions must inculcate the intricacies and richness of the culture-based approach in the delivery of the mathematics education curriculum. Early exposure of trainee teachers to available digital platforms for mathematics instruction delivery is key. Projects that seek to integrate cultural dimensions into mathematics problem-solving must be encouraged during mathematics teacher preparation, thereby laying a practical foundation for pre-service mathematics teachers to translate adopted culture-based paradigms into actionable instructional experiences for learners when they enter the field of practice.

This chapter has advocated for mathematics education instructional design that is rooted in the everyday lives of learners, with the hope of demystifying the subject of mathematics across all school levels. To achieve seamless technology-based mathematics teaching and learning, mathematics teachers must be properly trained in the content, pedagogy, and technology of mathematics instructional delivery that considers the culture of the learners. This approach serves not only to improve academic outcomes in mathematics but also to preserve the cultural heritage of the learners. The body of research reviewed in this chapter has affirmed the feasibility of using digital technology to blend culture-based mathematics education within mathematics teacher preparation programmes.

Despite the elegance of the conceptualisation discussed in this chapter, there must be a concerted effort by practitioners, in-service and pre-service mathematics teachers, educational policymakers, and the indigenous communities served by schools to translate tested templates into fruitful realities. Further research into understanding how the elements of ethnomathematics instructional design affect the effectiveness of pre-service teachers in diverse classrooms is of utmost importance. Future studies may explore the prospects of integrating specific folklore of indigenous communities into mathematics instructional design. Additional studies may test unique culture-based interventions within quasi-experimental setups to interpret the efficacy of the conceptual foundation documented in this chapter.

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