Towards an Alternative Innovative Socio-Cultural Instructional Model for Teaching Stoichiometry

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ABSTRACT

Secondary school students continue to present problems in conceptualising reaction stoichiometry in the chemistry learning area. The problem has negatively impacted the uptake of chemistry-related disciplines or those requiring chemistry knowledge at tertiary education level. The problem has been observed to be more prevalent among rural schools. This is despite the availability of the chemistry-rich cultural intellectual capital embedded in the everyday-life practices. The present article builds on Bhukuvhani et al.*'s (2020) findings from a case study on the impact of three selected aspects of culture on students' learning of stoichiometry. A chemistry class of 45 students at a rural secondary school in Guruve District, Zimbabwe, was purposively sampled. Interpretive analytical techniques were used to meticulously examine empirical findings on students' learning of stoichiometry in proposing a cultural heritage-inclined pedagogical model, the VALUES model. It was established that three selected aspects of culture impacted students' learning of stoichiometry in an interrelated manner. The VALUES model shows that each of the three aspects of culture influences students' understanding of stoichiometry in their unique ways, but in an interrelated and overlapping manner. The proposed VALUES model has six elements, namely, valued knowledge, argumentation, language system, understanding, engagement and support system. The model may guide the teaching of stoichiometry for conceptual understanding, utilising indigenous cultural knowledge and practices. The VALUES model increases epistemological access of science knowledge, thereby enhancing learning for understanding and curriculum socio-cultural relevancy*.

Keywords: stoichiometry, culture, socio-cultural instructional model, science education, curriculum innovation

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INTRODUCTION

Stoichiometry is that part of chemistry concerned with evaluating the results of quantitative measurements connected to chemical reactions and compounds (Schmidt & Jigneus, 2003). In the study of chemistry, stoichiometry forms the fundamental base for understanding other chemistry concepts. Mpofu *et al.* (2007) note that the understanding of concepts such as acids bases and salts, electrochemistry, chemical bonding, chemical equilibrium and solution chemistry highly depends on the conceptualisation of stoichiometry.

Chemistry is one of the key Science, Technology, Engineering and Mathematics (STEM) foundation learning areas. However, in separate studies, Kazembe and Musarandega (2012) and Mpofu *et al.* (2007) report that students who find stoichiometry difficult tend to drop chemistry at the early stages of their studies. This has negatively impacted the already low enrolments and success rates in tertiary education disciplines such as engineering, medicine, pharmaceutical, industrial manufacturing and other applied sciences disciplines. This is despite the fact that these learning areas are key drivers of economic growth, industrialisation and modernisation (Gadzirayi *et al.,* 2016).

Stoichiometry has attracted great interest among researchers in science education. However, most of these have focused on documenting students' learning difficulties in stoichiometry (Kazembe & Musarandega, 2012; Chandrasegaran *et al.,* 2009), students' conceptions of stoichiometry (Gauchon & Meheut, 2009), misconceptions (Mpofu *et al.,* 2007; Sanger, 2005), problem solving strategies (Bon Jaoude *et al.,* 2005) and teachers' pedagogical content knowledge (Okanlawon, 2010). The present article articulates how students learn stoichiometry for understanding in the context of their socio-cultural environments.

Emerging evidence points towards culture as likely to influence students' learning of science (Okere *et al.,* 2012). In Zimbabwe, the Education 5.0 philosophy encapsulates the notion of culture and heritage-based knowledge in the curriculum. The present research attempts to contribute to the discourse by proposing a socio-cultural instructional model for teaching stoichiometry, taking from the established relationship among the

considered aspects of culture with respect to how they impact students' learning (Figure 1).

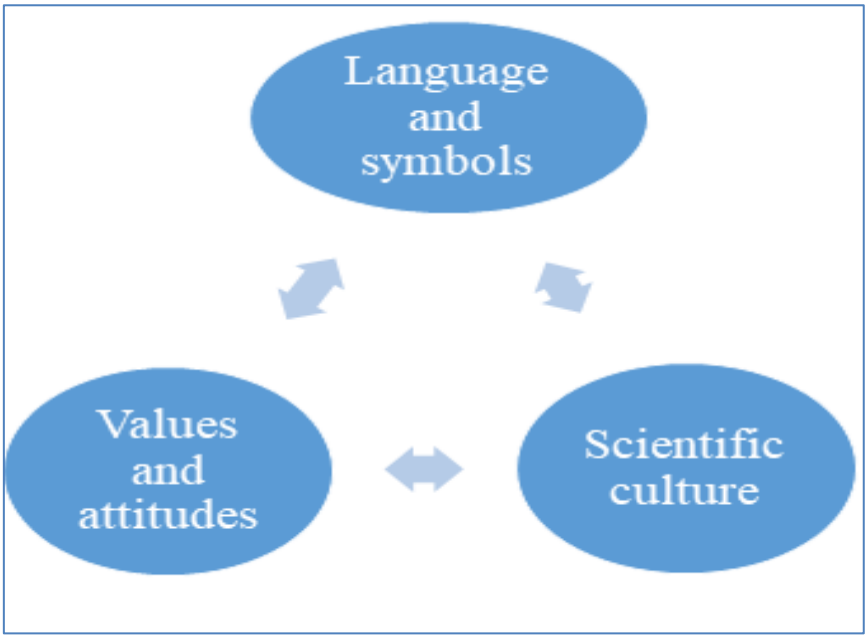


Figure 1*:* Interrelatedness of language, symbols, values, attitudes and scientific culture in influencing students' learning of stoichiometry **(**Bhukuvhani *et al.,* 2019, p. 259)

RESEARCH QUESTION

As a build-up to Bhukuvhani *et al.*'s (2019) report on the nature and severity of students' learning problems in stoichiometry, Bhukuvhani *et al.*'s (2020) report established the relationship and impact of the following three selected aspects of culture on students' learning of stoichiometry: language and symbols, values and attitudes, and the impact of scientific culture. The present research poses the following research question: What instructional model can be proposed to enhance students' conceptual understanding of stoichiometry?

METHODOLOGY

The purposive sampling technique was employed to select a chemistry class of 45 students at a rural secondary school in Guruve District in Mashonaland Central Province, Zimbabwe. The pragmatism philosophy

informed the study. The mixed methods approach was used, where research methods and modes of analysis were adopted on a fit-for-purpose basis. Specifically, the study employed the convergent parallel mixed research approach (Creswell & Plano, 2011), with predominance of interpretive methodological approaches to allow for contextual in-depth data generation and meaning-making thereof.

Data generation was achieved through the following tools: students' questionnaire, stoichiometry diagnostic test, stoichiometry class tasks, focus group interviews, semi-structured follow-up interviews, lesson observations and discussions on stoichiometry class tasks.

Thematic analysis was performed on students' responses with respect to how the three selected aspects of culture impact students' learning of stoichiometry. The linkages between these and emergent themes formed the basis for the formulation of the proposed instructional model presented in the findings and discussion section of this study.

FINDINGS AND DISCUSSION

THE INFLUENCE OF LANGUAGE AND SYMBOLS ON STUDENTS' CONCEPTUAL UNDERSTANDING OF REACTION STOICHIOMETRY

The findings have shown that the students had problems with both the language of instruction (English) and the subject matter language. The use of a second language may inhibit conceptual understanding. In most cases the students failed to interpret concepts or the demands of reaction stoichiometry problems due to non-comprehension of English both in communication and as the language of instruction in the learning of science. Johnstone and Selepeng (2007) point out that the English language is problematic in the conceptualisation of target aspects as there is a part of the working memory being solemnly set aside to handle language transfer instead of being wholly allocated to concept learning.

Notwithstanding that English as a foreign language has been perceived as difficult in the comprehension of the subject matter, all the students viewed English as an effective instructional language for learning reaction stoichiometry concepts in comparison to the local Korekore dialect. The

understanding of English did not, however, guarantee understanding of the subject matter. This is because the language used in reaction stoichiometry instruction is in a way alien to the students owing to its technical use peculiarities. The students mentioned that the Shona language or the locally spoken Korekore dialect may not be effective as it is difficult to translate and retain the meaning of some terms used in reaction stoichiometry from English to Shona. Thus, according to Lodge (2019), the Korekore language in this context is considered unsuitable for science classroom discourses.

However, the students indicated that they would understand reaction stoichiometry concepts if explanations were given in a language mostly used in the community. The students suggested code-switching as a viable option, thus confirming Gudhlanga's (2005) view that no language is more expressive than the other. This is despite the fact that the local languages have been relegated to restricted code status of Basil Bernstein's linguistic codes (Jones, 2013). Korekore is therefore in this respect used for purposes other than instructional, whilst English, as the elaborated code for official use including being the language of instruction, can be used interchangeably with Korekore.

In support of the findings of the present study and Gudhlanga's (2005) point of view, Bryan (2010) also suggests that some languages perceived to be inferior can be more expressive in particular contexts. Therefore, considering the use of English as the sole language in science teaching and learning may create incongruences between the science classroom experiences and students' real-life experience. These incongruences are a result of a lack of harmonisation between the society's socio-cultural values and linguistic backgrounds (Lodge, 2018).

THE INFLUENCE OF VALUES AND ATTITUDES ON STUDENTS' CONCEPTUAL UNDERSTANDING OF REACTION STOICHIOMETRY

The study findings concur with Sincero's 2019 study which indicates that the students' immediate environment and the cultural context provide learning through direct social interaction. This was evidenced by students' ability to cite and explain cultural practices which involve stoichiometry

determinations, including the artefacts used, the stoichiometry concept in the practices and the underlying chemistry.

The study also showed that the students viewed the cultural practices and experiences as being embedded with valuable knowledge on determination and quantification of substances. The study contends that the students acknowledged that stoichiometry determinations in cultural practices are mainly estimates as opposed to classroom chemistry. The classroom chemistry is characterised by more accurate determinations. The students, however, viewed that such knowledge, if integrated in their learning, may enhance their conceptual learning of reaction stoichiometry.

The study findings also revealed that reaction stoichiometry learning is not value free. There is a direct link between society-valued knowledge from the real world, cultural practices and students' understanding of related stoichiometry problems. The students showed some understanding of the associated concepts and performed better on the tasks as compared to those presented in abstract format as in the stoichiometry diagnostic test. In support, Odora-Hoppers (2002) notes that utilising value-laden knowledge promotes Afrocentrism, which in turn enhances curriculum quality in terms of relevance and conceptual learning, as is the case with this study.

THE INFLUENCE OF SCIENTIFIC CULTURE ON STUDENTS' CONCEPTUAL UNDERSTANDING OF REACTION STOICHIOMETRY

The study found out that the students' scientific culture was relatively low and contributed to their difficulties in solving reaction stoichiometry problems. Most students could neither give reasons in explaining phenomena nor present adequate reasons to justify the answers to problems on both the stoichiometry diagnostic test and the stoichiometry class tasks. This failure has exposed the existence of gaps in the development of critical thinking skills and logical reasoning. The gaps are compared to the students' performance as required by the revised curriculum framework for the primary and secondary education in Zimbabwe (2015-2022) (MoPSE, 2015).

Argumentation has been suggested as essential in developing learners' scientific thought systems (Erduran & Jimenez-Aleixandre, 2008). It

creates scientific thought systems in which students are taught to substantiate claims about phenomena through providing empirical data as evidence, and supporting statements as justifications for the claims. Students are further required to reveal their backings on underlying concepts assumptions and also offer rebuttals of counterclaims (Toulmin, 1958). Therefore, the development of scientific mind-sets and critical thinking skills among students enhances conceptual understanding.

ALTERNATIVE INSTRUCTIONAL MODEL FOR TEACHING STOICHIOMETRY FOR CONCEPTUAL UNDERSTANDING

The study proposes the use of the VALUES model as an alternative approach for teaching stoichiometry for conceptual understanding. The VALUES model is an attempt to address issues of access to quality science education in terms of relevance and the development of conceptual understanding among rural secondary school students. The model seeks to avail teaching strategies in the face of the availability of vast amounts of situated knowledge that can be harnessed for sustainable learning ventures.

The proposed VALUES model is presented in Figure 2. The model has six elements, that is, valued knowledge, argumentation, language system, understanding, engagement and support system.

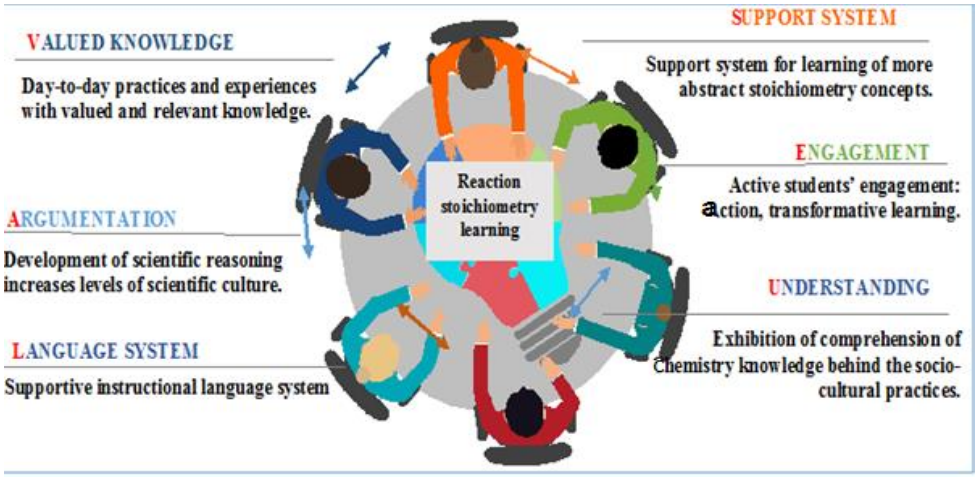


***Figure 2**:* The proposed VALUES model

VALUED KNOWLEDGE

The majority of the students (78.79%) scored above average with a mean score of 62.5% in the stoichiometry class tasks which were inclined to the students' cultural practices and experiences. This shows that the students tended to understand concepts that were related to their day-to-day practices and experiences. Such knowledge is valued as relevant in solving problems and decision-making on socio-scientific issues that require knowledge on quantification of substances. Chonkaew *et al.,* (2013), in their study conducted in Thailand, also report that students hardly develop conceptual understanding if the studied material has no established connection to real-world issues.

The case study revealed that students performed better in the stoichiometry class tasks in which the items were in the form of processes that the students were familiar with. The familiar concepts were accomplished better as compared to the stoichiometry diagnostic test where questions were of an abstract nature.

Abstract concepts with no links to real-world references for practicality and value attachment to such knowledge may be difficult for students. Aikenhead (2005), in her study in Canada, also observes that students rejected mechanistic mathematical descriptions of chemistry. In the case of the present study, those stoichiometry problems which did not have evident value to the students' day-to-day living were poorly handled, and the students could not provide explanations to the concepts contained therein.

The traditional practices and experiences have inherent important knowledge from which the students understand the related reaction stoichiometry concepts. The traditional practices brought familiarity to the concepts related to the practices. Students' ability to relate to cultural practices, processes and experiences which they viewed as applied stoichiometry concepts suggests that the valued knowledge from the students' home and immediate community may increase the students' levels of scientific culture. The knowledge of such practices and processes enhances students' understanding of the underlying science concepts behind the practices. Though the students professed that the ways in

which quantification of substances are done in the cultural practices are estimates, they still believed that these may be helpful in their learning of reaction stoichiometry in chemistry in which more accurate measurements are done. This shows that the knowledge from the two thought systems are at the equipollent adaptive co-existence outcome point (Ogunniyi, 2007). According to Ogunniyi's (2007) contiguity argumentation theory, equipollent adaptive co-existence means that the two competing thought systems are seen as equally powerful, adaptable, active, effective or significant in making sense of the observed phenomena.

The study proposes that educators carefully select culturally-inclined practices and processes in designing and formulating stoichiometry problems. Educators are further called upon to design problems whose knowledge is highly valued by the students in their contexts. The problems should be relevant in terms of applicability in decision-making and in solving societal socio-scientific issues. In this way, cognitive conflicts that may result from worldviews created from the two sources from which the students get their knowledge to explain phenomena, namely, the school science and their cultural practices and experiences, may be minimised. The result would thus be promoting what Aikenhead and Jegede (1999) and Aikenhead (1996) term smooth cultural border crossing in the learning of science concepts, in this case, reaction stoichiometry.

ARGUMENTATION

On the sets of stoichiometry tests administered, students either provided inadequate or no explanations at all for the answers they provided, thereby demonstrating their limited scientific reasoning. This may be a result of rote and mechanistic learning from both the school and the students' immediate home communities. The students failed to reason logically or provide explanations or justifications for why some phenomena exist, despite the fact that the students might have been familiar with the practice in their past and present societal contextual practice.

Toulmin's (1958) argumentation framework is relevant for the development of scientific reasoning and increases levels of scientific culture among students. The argument raised here is in support of the competence-based curriculum framework (2015-2022) for primary and secondary education in Zimbabwe. The curriculum emphasises the development of

critical thinking skills as one of the desired exit profiles among students (MoPSE, 2015).

Equally, even in the case that there are rebuttals which are also referred to as counter-claims, counter-arguments (Khun, 2010) or alternative claims, Berland and McNeill (2010) argue that these should also be supported by providing evidence and appropriate reasoning to justify the point of view. For example, follow-up interviews with students solicited their counter-arguments and the associated explanations to justify the counter-claims. The findings are in agreement with Osborne *et al.* (2004) and Khun (1991) who also note that arguments involving rebuttals are more difficult compared to those without, as the former require more intricate thinking.

The focus group interviews (FGIs) method used in the study agrees with Braund *et al.*'s (2013) view of argumentation as a learning method which capitalises on discussions and interaction within and among groups. The groups are a collective sense and meaning-making procedures in the social construction of the knowledge process (Vygotsky, 1978). The students, collectively through their FGIs discussions, generated knowledge from socio-cultural practices, processes and experiences in which quantification of substances and determinations (stoichiometry) are used.

LANGUAGE SYSTEM

In the learning of stoichiometry for conceptual understanding, language plays a significant role. Though the students had difficulties in understanding concepts through the use of English as the instructional language, they found English more appropriate as it helped them to have a better understanding of the subject matter. However, though the students found the use of the local Korekore language helpful in aiding them to understand, it may not on its own be used in the teaching and learning of stoichiometry. This is due to the fact that most of the concepts and terms used may not be easily translated and remain meaningful in reaction stoichiometry.

According to these findings, therefore, it is not enough for educators to be conversant in either English, the official instructional language as per the policy, or the subject matter language. Rather, it is important for educators to be competent in local languages for the purpose of code-switching.

Code-switching facilitates the use of local language equivalent or alternative science terminologies and explanations to phenomena in order to enhance students' learning in a complementary manner. It was notably observed from students' FGIs that some students could only express themselves in the local language. To this effect, Gudhlanga (2005) concurs in observing that no language is more expressive than the other. Although local African languages have been relegated to restricted code (Jones, 2013) statuses, it is important to note that if students use a language which they already know, effective education is achieved (Babaci-Wilhite, 2019). This is because a community's own language is embedded with both local linguistic and cultural knowledge wealth. Brock-Utine (2016) weighs in the discourse by arguing that the use of students' local home languages enhances scientific reasoning, understanding of content knowledge as well as self-efficacy. However, earlier studies, for example, Jongore *et al.* (2013), lament the poor base for first languages in Zimbabwe.

UNDERSTANDING (COMPREHENSION)

Understanding of the fundamental chemistry concepts is essential for students' conceptual understanding of reaction stoichiometry. The study revealed the prominence of rote learning and cramming at the expense of learning for understanding. However, where students were familiar with and valued the practices involved in the stoichiometry class tasks (see valued knowledge above), they exhibited some knowledge of chemistry behind the practices. Where students demonstrated knowledge of chemistry behind traditional practices, they also showed an increased level of scientific literacy, thereby enhancing learning for understanding. Posner *et al.* (1982) explain that for a scientific concept to be accommodated for learning for understanding, it should be plausible, intelligible and with capacity to solve problems requiring practical stoichiometry knowledge in socio-cultural settings.

Students' understanding is also brought about by interrogating processes and critiquing answers given to explain particular phenomena as already explained under argumentation. Follow-up interviews with students revealed that knowledge gained through practical-based activities

enhances students' understanding. The following responses support the observation:

> *LEARNING DOING PRACTICAL WORK. (INT/SRN 6)*
> We must do practical work and learners must have all equipment used in stoichiometry. (INT/SRN 1)
> By having many experiments and more exercises. (INT/SRN 12, 19)
> Experiments and demonstrations because they are easy to understand. (INT/SRN 31)
> Experimental practice in the laboratory will help us to understand more. (INT/SRN 39)

ENGAGEMENT

The theoretical framework for this study insists that the situated cognition theory views learning as participation in a community of practice. Students' engagement is key in achieving meaningful learning. Practical learning encourages the movement of students from being mere observers to experts by actively participating in the community of practice (Lave & Wenger, 1991).

The researchers observed that transformative learning and the 6E+S (Engage, Explore, Explain, Elaborate, Evaluate, Extend and Standards) instructional model possess very important stages which involve active engagement of students in real-world concrete experiences and practices. The VALUES model is thus informed by transformative pedagogy and the 6E+S instructional model. Learning activities that engage students challenge their existing knowledge and stimulate curiosity, thereby encouraging them to pursue answers for their own questions (Curriki, 2008).

Through actively engaging students, educators tap into contextual scientific knowledge reservoirs within the local indigenous societies, which in turn promotes curriculum relevance. According to Pesanayi *et al*. (2019), situated engagement enhances quality education in terms of relevance, and also aids in the development of higher-order systems thinking and processing skills among students. However, the solicited prior knowledge should comply with the set curriculum standards (the S in the 6E+S model) (Curriki, 2008). Of note is that engagement is key in the application of social constructivist approaches, as the solicited situated

prior knowledge forms the base on which the students create their own new knowledge.

Some self-built experiments (Bhukuvhani *et al.,* 2013) may be designed and carried out to support delivery of authentic and engaged learning. The self-built experimental activities make it possible for the students to realise practical learning in an unspectacular manner, particularly in rural setups and without diluting the curriculum (Bhukuvhani *et al.,* 2013; Bhukuvhani *et al.,* 2012).

Carefully selected and designed practical activities are important in the development of learning for conceptual understanding. Practical activities afford the students authentic learning through observations, acquisition, application and consolidation of ideas (Burke, 2009).

SUPPORT SYSTEM

The students had problems in their developing of understanding across all the stoichiometry concepts. For example, some students could not write balanced chemical equations because of incorrect representations of chemical formulae of the reactants and products. In cases like this, educators may support students' learning of writing and balancing of chemical equations through scaffolding. The concept of writing balanced chemical equations can be developed by scaffolding students' knowledge on related concepts such as chemical bonding and reaction mechanisms. These concepts may be taught first so that the students can build new knowledge upon the platform set by the preceding concepts.

The following abstract stoichiometry concepts were found to be problematic for the students: stoichiometric ratios, writing and balancing of chemical equations, limiting reagent and other related chemistry concepts that are required for the conceptual understanding of reaction stoichiometry. The learning of such reaction stoichiometry concepts may be supported by the use of visual models, simulations and virtual reality systems as supported by the following students' responses during the follow-up semi-structured interviews. The students were responding to the questions on which strategies may be employed in order to support the

learning and understanding of more abstract reaction stoichiometry concepts:

> Learning by doing practical work and being shown videos of what we have learnt. (INT/SRN 6)
> By the provision of Internet for research. (INT/SRN 16)
> By means of computers, experiments and book references, so we can visualise abstract concepts. (INT/SRN 31)

The VALUES model extends knowledge in the culture-science learning discourse. Since cognitive conflicts impair conceptual understanding, Chiromo (2015, p. 164), in a related prior study, proposes a cognitive management pedagogy cycle which recognises the need for culturally-appropriate pedagogies. The VALUES model provides for a possible format which such culture-sensitive pedagogies may take and be utilised.

CONCLUSION

The VALUES model is a systems model whose elements (valued knowledge, argumentation, language system, understanding, engagement and support system) are interrelated and support one another in promoting and developing a quality curriculum. The quality of the curriculum is in terms of relevance and learning for conceptual understanding. The model is premised on the established relative impact of three selected aspects of culture: language and symbols, values and attitudes, and scientific culture on students' learning of reaction stoichiometry. The current study is with particular reference to a rural secondary school.

As already alluded to, the VALUES model extends knowledge in the culture-science learning discourse. Cognitive conflicts impair conceptual understanding. Therefore, in order to achieve the desired conception among students, it is pertinent to take the appropriate cultural pedagogies. However, prior studies on this issue could not establish the specific nature the culture-sensitive pedagogies would take. The VALUES model is a culture-sensitive instructional strategy which attempts to cover the gap by providing a possible format which such culture-sensitive pedagogies may take and be utilised.

If used with consistency, the proposed VALUES model may greatly enhance students' learning for the understanding of stoichiometry as it seeks to increase epistemological access to science knowledge by reducing abstraction through utilisation of socio-cultural lived experiences and practices.

REFERENCES

Aikenhead, G. S. (1996). Science education: Border crosing into the subculture of science. *Studies in Science Education*, *2*(7), 1-52.

Aikenhead, G. S. (2005). Cultural influences on the discipline of chemistry. In *88th Canadian Chemistry Conference* (pp. 1-8). Saskatoon: University of Saskatchewan.

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural science education : A cognitive explanation of a cultural phenomenon, *36*(3), 269-287.

Babaci-Wilhite, Z. (2019). Educational tools to teach STEAM subjects: Integrating linguistic rights, collaborations, and critical thinking. In Babaci-Wilhite (Ed.), *Promoting language in STEAM as human rights in education*. Singapore: Springer. https://doi.org/https://doi.org/10.1007/978-981-13-2880-0_1

Berland, L. K., & McNeill, L. (2010). A learning progression for scientific argumentation: Understanding students' work and designing supportive instructional context. *Science Education*, *94*, 765-793.

Bhukuvhani, C., Chiromo, A., & Chukunda, C. (2019) Towards a framework for understanding the influence of selected aspects of culture on secondary school students' learning of stoichiometry: Insights from a preliminary study. *Zimbabwe Journal of Educal Research, 31* (3), 391-417.

Bhukuvhani, C., Chiromo, A. & Chikunda, C. (2020) Influence of culture on secondary school students' learning of stoichiometry: A case of a Guruve district school, Zimbabwe. *Journal of New Vision in Educational Research*, *1* (2), 245-262.

Bhukuvhani, C., Mupa, M., Mhishi, M., & Dziva, D. (2012). Science practical work instructional technologies and instructional technologies in science teacher training: A case study in Zimbabwe. *International Journal of Education & Development Using Information & Communication Technology*, *8*(2), 17-27.

Bhukuvhani, C., Sana, A., & Tigere, A. (2013). Self-built experimental projects (SBEP): Curriculum engineering for science practical work in open and distance learning environment. *International Journal of Curriculum Development and Planning*, *2*(5).

Braund, M., Scholtz, Z., Sadeck, M., & Koopman, R. (2013). First steps in teaching argumentation: A South African study. *International Journal of Educational Developmnt*, *33*, 175–184. https://doi.org/ http://dx.doi.org/10.1016/j.ijedudev.2012.03.007

Brock-Utine, B. (2016). English as language of science and technology. In *Human rights in language and STEM education* (pp. 111-127).

Bodner, G. M., & Bhattacharyya, G. (2005). A cultural approach to problem solving. *Educacion Quimica*, *16*(2).

BonJaoude, S., & Barakat, H. (2003). Students' problem solving strategies in stoichiometry and their relationships to conceptual understanding and learning approaches. *Electronic Journal of Science Education*.

Burke, K. (2009). *How to assess authentic learning*. Thousand Oaks, CA: Corwin.

Chandrasegaran, A. L., Treagust, D. F., Waldrip, B. G., & Chandrasegaran, A. (2009). Students' dilemmas in reaction stoichiometry problem solving: deducing the limiting reagent in chemical reactions. *Chemistry Education Research*, 14-23.

Chiromo, A. S. (2015). *Zimbabwean rural day secondary school students' management of conflicts arising from studying the human reproductive system*. Harare: University of Zimbabwe.

Chonkaew, P., Sukhummek, B., & Faikhamta, C. (2013). Development of Analytical Thinking Ability and Attitudes towards Science Learning of Grade-11 Students through Science Technology Engineering and Mathematics (STEM Education) in the Study of Stoichiometry. *Chemistry Education Research and Practice*, 1-25.

Curriki. (2008). 6E+S Lesson Plan. Retrieved September 21, 2017, from http://www.curriki.org/oer/6E-S-Lesson-Plan.

Erduran, S., & Jimenez-Aleixandre, M. P. (Eds.). (2008). *Argumentation in science education: Perspectives from classroom-based research*. New York: Springer Publishing Co.

Gadzirayi, C. T., Bongo, P. P., Ruyimbe, O., Bhukuvhani, C., & Mucheri, T. (2016). *Diagnostic study on the status of STEM education in Zimbabwe*. Harare: Bindura University of Science Education and Higherlife Foundation.

Gauchon, L., & Meheut, M. (2007). Learning about stoichiometry: from students, preconceptions of the concept limiting reactant. *Chemistry Education Research and Practice*,*8*(4), 362-375.

Gudhlanga, E. S. (2005). Promoting the use and teaching of African languages in Zimbabwe. *Zimbabwe Journal of Educational Research*, *17*(1), 54-68.

Jones, P. E. (2013). Bernstein's "codes" and linguistics of "deficit." *Language and Education*, *27*(2), 161-179.

Jongore, M., Chirimuuta, C., Bhukuvhani, C., & Zuvalinyenga, D. (2013). The Zimbabwean first languages seem to be slowly dying a natural death: A case of university students' academic writing. *Greener Journal of Educational Research*, *3*(7), 318–325.

Johnstone, A. H., & Selepeng, D. (2007). A language problem revisited. *Chemistry Education: Research and Practice in Europe*, *2*(1), 19-29.

Kazembe, T. C., & Musarandega, A. (2012). Student performance in A-level chemistry in Makoni district, Zimbabwe. *Eurasian Journal of Physics and Chemistry Education*, *4*(1), 2-29.

Khun, D. (1991). *Thinking as argument*. Cambridge: Cambridge University Press.

Khun, D. (2010). Teaching and learning science as argument. *Science Education*, *94*, 810-824.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lodge, W. G. (2018). *The accessibility of science instructions to Jamaican students*. University College London (UCL).

Lui, A. (2012). Teaching in the zone: An introduction to working within the zone of proximal development (ZPD) to drive effective early childhood instruction. Retrieved from www.childrensprogress.com

Mezirov, J. (1997). Transformative learning: Theory to practice. *New Directions for Adult and Continuing Education*, *4*, 5-15.

MoPSE. (2015). *Zimbabwe education blueprint 2015-2022 - Curriculum framework for primary and secondary education*. Harare: Ministry of Primary and Secondary Education (MoPSE).

Mpofu, V., Kusure, L., Nhenga, J., & Zishiri, G. (2007). Advanced level chemistry students' understanding of stoichiometry: Evidence from four schools in Zimbabwe. *Southern African Journal of Education Science and Technology*, *2*(2), 90-100.

Nkala, S. (2014, January 27). Gukurahundi blamed for poor results. *Southern Eye*. Retrieved from https://www.southerneye.co.zw/2014/01/27/gukurahundi-blamed-poor-results/

Odora-Hoppers, C. A. (2002). *Indigenous knowledge and the integration of knowledge systems: Towards a philosophy of articulation*. Claremont: New Africa Books.

Ogunniyi, M. B. (2007). Teachers' stances and practical arguments regarding a science indigenous knowledge curriculum. *International Journal of Science Education*, *29*(10), 1189-1207.

Okanlawon, A. E. (2010). Teaching reaction stoichiometry: Exploring and acknowledging Nigerian chemistry teachers' pedagogical content knowledge. *Cypriot Journal of Educational Sciences*, *5*, 107-129.

Okere, M. I. O., Keraro, F. N., & Anditi, Z. (2012). Pupils' beliefs in cultural interpretations of "heat" associated with anger: A comparative study of ten ethic communities in Kenya. *European Journal of Educational Research*, *1*(2), 143-154.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argument in school science. *Journal of Redearch in Science Teaching*, *41*(10), 994-1020.

Pesanayi, T., O'Donoghue, R., & Shava, S. (2019). Think piece: Situating Education for Sustainable Development in Southern African philosophy and contexts of socio-ecological change to enhance curriculum revelvance and common good. *Southern African Journal of Environmental Education*, *35*, 213-221.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211-227.

Sanger, M. (2005). Evaluating students' conceptual understanding of balanced equations and stoichiometric rations using a particulate drawing. *Journal of Chemical Education*, *82*(1), 131-134.

Schmidt, H.-J. and Jigneus, C. (2003). Students' strategies in solving algorithmic stoichiometry problems. *Chemistry Education: Research and Practice*, *4*, 305-317.

Sincero, S. M. (2019). Ecological system theory. Retrieved January 21, 2019, from https://explorable.com/ecological-systems-theory.

Stewart, M. (2012). Understanding learning: Theories and critique. In L. Hunt & D. Chalmers (Eds.), *University teaching in focus: A learning-centred approach* (pp. 1–15). Victoria: ACER Press and Routledge.

The Standard. (2014, February 3). Zimbabwe: Matabeleland's Low Pass Rate Worrying. *The Standard*. Retrieved from https://allafrica.com/stories/201402031997.html

Thomas, L. M. (2012). *Teaching reactions and stoichiometry: A comparison of guided inquiry and traditional laboratory activities*. Michigan State University.

Toulmin, S. (1958). *Uses of argument*. Cambridge: Cambridge University Press.

Vygotsky, L. S. (1978). *Mind in society*. London: Harvard University Press.

ZBC. (2019). Nkayi schools record 0% pass rate. Zimbabwe: Zimbabwe Broadcasting Corperation (ZBC). Retrieved from www.zbc.co.zw

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*, 35-62.