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Development, adaptation and validation of instruments for assessing Namibian students' beliefs about nature of science

Summary of the PhD Dissertation

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CONTEXT AND PROBLEM STATEMENT

Namibia has set itself a vision to become an industrialised nation by the year 2030 (Eita, Appolus, & Ndimbira, 2004). Namibia Vision 2030 envisages seeing the country developing from a literate society to a knowledge-based society. A knowledge-based society is one where knowledge is created, transformed, and used for innovation to improve the quality of life (Ministry of Education, 2010). Namibia recognises the importance of scientific literacy by making science, technology and innovation a priority in its development endeavours such as Vision 2030 and the National development plans (NDPs). The National Curriculum for Basic Education (NCBE) states that Natural Sciences are part of the main drivers of the transformation of society and the world. According to the NCBE, scientific literacy which is the understanding of scientific processes, the nature of scientific knowledge, and the ability to apply scientific thinking and skills, is “indispensable today” (Ministry of Education, 2010, p. 12). Therefore, Natural Sciences area of learning contributes to the foundation of a knowledge-based society by empowering learners with the scientific knowledge, skills and attitudes to formulate hypotheses, to investigate, observe, make deductions and understand the physical world in a rational scientific and sustainable way.

Several reforms have taken place in the Namibian education system since independence in 1990, particularly in curriculum and assessment areas. However, such reforms did not fully address scientific literacy assessment at any level of schooling despite calls to prioritise science, technology and innovation in the country. In primary education, the only scientific and reliable diagnostic assessment that attempts to measure students’ science literacy are the Standardized Achievement Tests (SAT) that were introduced in 2009 (Iipinge & Likando, 2012). However, these tests too fell short of assessing scientific literacy in the broader sense of the concept (Wenning, 2006) as they only assess students’ achievement of disciplinary science upon completion of Grade 7 science curriculum and not on scientific inquiry and the nature of science neither on the application of scientific literacy needed for success in everyday life (Németh & Korom, 2012). In secondary education, there are two certification examinations at Grades 10 and 12. Contrary to primary education there is no diagnostic assessment of scientific literacy taking place in the secondary education phase. Furthermore, scientific inquiry and nature of science are not taught directly in the science curriculum. Science teachers are required to incorporate these skills in the teaching of the content.

The current forms of inquiry are also viewed as over-simplified thus making students think of science as the accumulation of simple facts rather than the construction and revision of models and theories about the natural world (Gu & Belland, 2015). In response, there has been a shift of learning goals in recent years, from content knowledge to understanding of the nature of science. This shift emphasises the epistemic aspect of scientific inquiry needed to help students develop 21st century skills. Students need to develop sophisticated understanding of the nature of scientific knowledge and how such knowledge is constructed (Gu & Belland, 2015). However, the assessment of science knowledge in Namibian schools does not include this aspect of scientific literacy despite that the national curriculum advocates for students to develop into scientific literate citizens (Ministry of Education, 2010). All assessments in science learning mainly focus on subject content knowledge, hence, there is hardly any means through which to ascertain whether students are acquiring the understanding of the nature of science. One way to ascertain students' understanding of the nature of scientific knowledge is to assess their beliefs.

Besides, motivation to learn science has been linked with beliefs about the nature of scientific knowledge and knowing and most of the conclusions drawn from such links support the notion that sophisticated beliefs may positively relate to motivation particularly self-efficacy. Whilst less sophisticated (absolutist) beliefs were associated with negative self-judgement. For these reasons, motivation was also view as a relevant component worthy of inclusion in this study.

Afterall, advancing students' beliefs about the nature of scientific knowledge and knowing has featured prominently in recent research in science education (Chen, 2012; Chen, Metcalf, & Tutwiler, 2014; Conley, Pintrich, Vekiri, & Harrison, 2004; Tsai, Jessie Ho, Liang, & Lin, 2011). This is also the case with studies that link motivation to learn science with scientific epistemic beliefs (Chen & Pajares, 2010; Paulsen & Feldman, 2007; Tuan, Chin, & Shieh, 2005). A search for studies including online publications in repositories of local institutions in Namibia as well as on several international databases did not yield any reports of similar studies done in Namibia. Most of what is known about students' views about the nature of scientific knowledge or scientific epistemic beliefs and motivation to learn science comes from other countries, particularly the western world and the far east.

THEORETICAL BACKGROUND

Several reforms have taken place in the Namibian education system since independence in 1990, particularly in curriculum and assessment areas (Iipinge & Likando, 2012). However, none of the reforms provided explicit guidelines on how to teach the nature of science, particularly in science subjects' specific curricula.

Nature of science is viewed by some science educators as an affective learning outcome and not as a cognitive or instructional outcome of equal status with traditional subject matter outcomes (Lederman, 2006; Schwartz, Lederman, & Crawford, 2004). It is also not taught explicitly and reflectively in basic education science curricula, despite such curricula advocating that understanding of nature of science is a prerequisite for scientific literacy development. It is assumed that students would acquire the understanding of nature of science just by doing science and inquiry activities (Khishfe, 2008). This approach was found to be ineffective (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). For this reason, Khishfe and Abd-El-Khalick (2002) suggested that understanding of NOS should be considered as a cognitive learning outcome and should be taught explicitly rather than expected to being acquired through some kind of “osmotic process” while engaging in regular science activities (p. 554). Research in many parts of the world reveals that students and teachers do not possess appropriate conception of nature of science (Bell, Blair, Crawford, & Lederman, 2003; Khishfe & Abd-El-Khalick, 2002; Lederman, 1992; Meichtry, 1992; Moss, Abrams, & Robb, 2001). There is also no shortage of instruments for assessing students’ views of nature of science (Lederman et al., 1998). However, no such instruments appear to exist in Namibia. Similarly, research on nature of science are hardly done in Namibia. The development of a valid instrument for assessing students’ view of nature of science in Namibia was one of the goals of the present study.

The concept NOS has been commonly used to refer to “the epistemology of science, science as a way of knowing or the values and beliefs inherent to the development of scientific knowledge” (Lederman, 1992, p. 331; 2007). However, there still exists disagreement among philosophers of science, historians of science, scientists and science educators on the specific definition of the concept (Abd-El-Khalick, 1998). In recent decades, there has been a notable consensus among science educators pertaining the level of simplicity of the aspects of the nature of science that is suggestively accessible and appropriate to basic education science students. This concurrence is based upon the understanding that scientific knowledge is tentative; empirically-based; there is no single “Scientific Method”; subjective; based on imagination and creativity; socially and culturally embedded; observation and inference are different; and theories and laws are distinct kinds of knowledge (Abd-El-Khalick et al., 2017; Abd-El-khalick & Lederman, 2000; Lederman, 2007; McComas, 2008; Niaz, 2008; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003).

A variety of rationales for teaching nature of science has been suggested by science educators and researchers (Virginia Mathematics and Science Coalition, 2013). Bell (2008) argues that an accurate understanding of the nature of science helps students identify the strengths and limitations of the scientific knowledge, develop accurate views of how science can and cannot answer. Moreover, research suggests that teaching students the nature of science can facilitate the learning of science subject content and increase student achievement (Cleminson, 1990; Driver, Leach, Millar, & Scott, 1996; Peters, 2012; Songer & Linn, 1991).

Beside the eight general aspects conceptualisation, was the suggestion that scientific epistemic beliefs (SEB) had four dimensions (Conley et al., 2004).They are source; certainty; development; and justification. Epistemic beliefs have been associated with learning and academic achievement in science (Cano, 2005; Stathopoulou & Vosniadou, 2007; Trautwein & Lüdtke, 2007). These studies highlighted the importance of exploring student's views about the nature of scientific knowledge with a view to help them better understand science concepts.

Motivation to learn science has been linked with beliefs about the nature of scientific knowledge (Chen & Pajares, 2010; Paulsen & Feldman, 2007; Tsai, Jessie Ho, Liang, & Lin, 2011) and most of the conclusions drawn from these studies support the notion that sophisticated beliefs may positively relate to motivation particularly self-efficacy. Whilst less sophisticated (absolutist) beliefs were associated with negative self-judgement. For these reasons, motivation was viewed as a relevant component worthy of inclusion in this study.

Students' self-efficacy, science learning value, learning strategies, learning goal and the learning environment stimulation are some of the important motivational factors attributable to science learning motivation (Tuan et al., 2005). Such factors were adapted for this study as the basis for assessing Namibian Grade 12 students' motivation to learn science.

RESEARCH AIMS AND EMPIRICAL STUDIES

The overall aims of this research were to develop, adapt and psychometrically validate questionnaires for assessing senior secondary students' beliefs about the nature of science and motivation to learn science in the cultural context of Namibia.

In this research, four empirical studies were carried out. Study 1 was a piloting of the new questionnaire developed to assess beliefs about nature of science and scientific inquiry, conducted subsequent to its development, with the aim of validating its content using secondary school science teachers in Namibia. As part of the continued validation of the new questionnaire, Study 2 aimed at exploring the factorial validity of the eight general aspects conceptualisation of nature of science that underpinned the development of the new questionnaire termed 'Beliefs About the Nature of Science' (BANOS) and to assess senior secondary students' beliefs about the nature of scientific knowledge.

The review of literature revealed that motivation to learn science has been linked to beliefs about the nature of science. For this reason, Study 3 aimed to adapt and conduct a cross-cultural validation of the Students' Motivation Towards Science Learning (SMTSL) questionnaire in the cultural context of Namibia. Study 4 was aimed at adapting and conducting a cross-cultural validation of the SEBs questionnaire in the cultural context of Namibia using senior secondary science students.

STUDY 1: Validation of an instrument to assess beliefs about nature of science and scientific inquiry in Namibia – a pilot study

The reliability of this questionnaire was very high. This shows that the instrument overall had very high reliability. The average inter-item correlation for the items at this stage was within prescribed range. This indicate that items relate to each other fairly well (Piedmont, 2014) and therefore in the context of this study, they may be suitable for measuring beliefs about the nature of science and scientific inquiry in Namibia. The mean item-total correlation was also desirable, suggesting that each item in the scale was measuring the same construct.

The response pattern revealed an interesting trend in the science teachers' beliefs about the nature of science and scientific inquiry. It shows that teachers' beliefs about the tentative nature of science; observations and inferences; and scientific inquiry were quite similar. This meant teachers' beliefs about these subscales were quite informed because option 4 in the scale represents 'agree'. However, the response pattern for five of the subscales namely, the scientific method; the subjective; imaginative and creative; socio-cultural embeddedness and; scientific theories and laws, show substantive amount of uncertainty in the teachers' beliefs. This suggests that they were not sure whether to agree or disagree with the statements. Furthermore, teachers' beliefs about the empirical nature of science was more confounding because they generally disagreed with this notion.

The results also showed that there was no significant difference in terms of the gender of the teachers. It can be concluded that gender does not seem to influence science teachers' beliefs about nature of science and scientific inquiry within this sample. Similarly, there was no significant difference in beliefs based on the type of science subject (Biology or Physical Science) teachers taught. Results further showed that there was no significant difference in beliefs between the different ranges of years of science teaching experience. Suggesting that teaching experience did not influence teachers' beliefs about nature of science and scientific inquiry in this sample.

STUDY 2: Exploring the factorial validity of the beliefs about nature of science questionnaire (BANOS)

The reliability of the resultant 16-item questionnaire was good. The reliability of individual factors was also reasonable. These results suggest that the questionnaire had good overall reliability for the sample used. Exploratory factor analysis produced a final interpretable five-factor structure consisting of 16 items after the culling of cross-loading items and the factor solution accounted for 67.73% of the total variance. The five factors were retained based on eigenvalues greater than 1 criterion. The average variance extracted (AVE) values for the five latent factors ranged from .46 to .64. The composite reliability (CR) values ranged from .75 to .81. Although the AVE value for one factor was below the acceptable minimum cut-off point of .50, convergent validity may still be adequate because all latent factors had CR values above .70 (Fornell & Larcker, 1981). Malhotra and Dash (2011) also argued that the AVE is often too strict and validity can be established through CR alone.

Discriminant validity was assessed by comparing the square root of the AVE with the correlation of latent factors (Hair et al., 2016). The square root of the AVE should be greater than .50 (Fornell & Larcker, 1981) and greater than inter-latent factor correlations within the model (Hair, Black, Babin, & Anderson, 2010). It was found that not all latent factors met the requirements and their discriminant validity may not be adequate, thus construct validity may be inadequate. Confirmatory factor analysis results showed that the five-factor model had poor statistical fit for the data, with only two fit indices meeting the requirements. However, the four-factor model had better statistical fit for the data, though still below recommended thresholds.

STUDY 3: A cross-cultural validation of adapted questionnaire for assessing motivation to learn science among grade 12 students in Namibia

The overall reliability of the adapted questionnaire was acceptable. Suggesting that the questionnaire had reasonable overall reliability for the sample used although some individual factors showed reliability values below recommended thresholds. Exploratory factor analysis yielded five factors with eigenvalues greater than 1 and the factor solution accounted for 56.1% of the total variance.

Confirmatory factor analysis showed that the five-factor measurement model fitted the data very owing to six good fit indices.

The AVE values for the five latent factors ranged from .32 to .47. The CR values ranged from .63 to .78. Although the AVE values for all latent factors were below the preferred minimum cut-off point of .50, convergent validity may still be adequate because most factors had AVE values above .40 (minimal acceptance level) except for two factors namely achievement goal and science learning value; and all factors had CR values above .60 (Fornell & Larcker, 1981). However, such finding is not surprising because the reliability of the adapted questionnaire in the Namibian cultural context was quite similar to the reliability in previous studies (Dermitzaki, Stavroussi, Vavougios, & Kotsis, 2013; Yilmaz & Çava,

2007) that adapted the same questionnaire in different cultural settings of Turkey and Greece respectively.

It was found that the square root of the AVE was greater than .50 and greater than inter-latent factor correlations within the model. All latent factors support these requirements and the discriminant validity is confirmed. In conjunction with convergent validity, these results indicate that there was reasonable construct validity. These findings can be interpreted to suggest that the adapted instrument is suitable for assessing Namibian Grade 12 science students' motivation to learn science particularly in large scale cross-sectional studies.

STUDY 4: Instrument adaptation, cross-cultural validation and assessment of students' scientific epistemic beliefs

The reliability of individual dimensions as well as overall was acceptable. The overall level of beliefs was fairly low for the two naïve dimensions namely source and certainty but were higher for the sophisticated dimensions namely development and justification. Though these results are similar to the findings in the original questionnaire, it is difficult to interpret students' beliefs accurately due to the cross-sectional nature of this study.

An assessment of convergent validity showed that almost all loading values of the items were significant and higher than .50, indicating that in most cases more than 50% of the variance is explained by the dimensions. The CR values all exceeded the recommended cutoff value of .70 (Fornell & Larcker, 1981). The AVE values for three of the dimensions (source, certainty, and development) met the minimum cutoff point of .50 while the AVE value for the justification dimension was .40. The CR values ranged from .80 to .83. Although one dimension had the AVE value below the preferred minimum cut-off point of .50, convergent validity may still be adequate because the other three dimensions had AVE values of .50 and all dimensions had CR values above .70 (Fornell & Larcker, 1981). Discriminant validity was tenable as all dimensions of beliefs support the precedent requirements for this criterion and together with convergent validity, construct validity is confirmed.

The measurement model fitted the data very well with all six fit indices meeting the prescribed threshold (Garson, 2015). Previous studies (Cano, 2005; Stathopoulou & Vosniadou, 2007; Trautwein & Lüdtke, 2007) have suggested that epistemic beliefs may have an influence on students' academic achievement. The regression model was significant, however, only two dimensions namely certainty and justification statistically significantly predicted achievement in science for this sample. Source and development negatively predicted achievement in science but the regression weights were not statistically significant.

The study found that there was statistically significant difference in beliefs about source of scientific knowledge in terms of gender. Female students showed slightly more sophisticated beliefs about source of scientific knowledge than male students, however, the effect size was very small, probably owing to the large sample size. Nonetheless, this was a positive finding considering that this is a validation study. The results were congruent with Cano (2005), although using different instruments, it was found that girls' epistemological beliefs about knowledge and learning, at all school levels, were more realistic than for the boys.

There was no statistically significant difference in beliefs about other three dimensions in terms of gender. This is in line with previous research findings which claimed that there were no important differences in epistemological thinking in terms of gender. With regard to grades, there was a statistically significant difference in beliefs about source and certainty between grades. Grade 11 students showed more sophisticated beliefs about source than Grade 12 students, however, the difference was very small. Alternately, Grade 12 students showed more sophisticated beliefs about certainty than Grade 11 students, which is also a small but significant difference. These results are in conflict with the hypothesis that Grade 12 students would have more sophisticated beliefs than Grade 11 students, because they have been studying science longer. The results showed that there was no statistically significant difference in the means of high and low SES across all four dimensions of beliefs. Both groups showed overall lower scores on source and certainty and higher scores on development and justification.

The results suggest that regardless of the SES, students possessed less sophisticated beliefs about source and certainty but possessed more sophisticated beliefs about development and justification. These findings are contrary to what was reported about SES in the original study (Conley et al., 2004). It was reported that low SES students scored lower in all four dimensions of beliefs than average SES students. Suggesting that low SES students appeared to possess less sophisticated epistemic beliefs.

CONCLUSION

This research endeavoured to develop, adapt and validate instruments for assessing Namibian secondary school students' epistemic beliefs about the nature of scientific knowledge and associated components such as motivation to learn science. It was focused on the sample of the population that is in the exit phase of the Namibian basic education phase, the senior secondary phase (Grades 11 and 12). Through the review of literature, it was found that there was lack of research in Namibia regarding students' epistemic beliefs about the nature of science. Although numerous instruments for assessing students' beliefs about nature of science exist, their psychometric validity has been uncertain because many such instruments were validated through qualitative methods only and as such limited the confidence in their use. Similarly, there were no psychometrically validated instruments for assessing students' epistemic beliefs about nature of science neither motivation to learn science in the Namibian context. The research was made up of four studies. Findings from both studies point in a positive direction despite some inconsistencies in the measurement model fitness of the new BANOS questionnaire that was developed. The adapted instrument showed better results suggesting their suitability for use in the Namibian context. Due to the pioneering nature of this research and considering its limitations, several recommendations were made in terms of suggestions for further research among Namibian students and science teachers.

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