STUDENT, TEACHER AND SCHOOL RELATED VARIABLES AS DETERMINANTS OF CHEMISTRY ACHIEVEMENT IN KENYA: A CASE OF THE MOLE CONCEPT

Nicholas T. Wanjala
Kenyatta University
nicholastwoli@yahoo.com

Janet B. Akala
Masinde Muliro University
akalammust@gmail.com

David W. Khatete
Kenyatta University
dkhatete@yahoo.co.uk

The Mole Concept is a threshold Concept and has often been referred to as an area of troublesome knowledge. The study constructed and tested a model for providing a causal explanation of secondary school achievements in Mole Concept area of chemistry in terms of student variables which emphasized gender, spatial ability, mathematical ability, socio-economic status, attitude; teacher's variables considered as mode of instruction, teaching experience, teaching qualifications, teacher attendance of inset while School variables included resources. A descriptive survey design was adopted for the study. The population was made up of three hundred and eighty four form four secondary school students and their teachers from thirty stratified selected schools. Five sets of instrument were used and these included Chemistry Teachers' Questionnaire (CTQ), Mole Concept Students Attitude Scale (MCSAS), Mole Concept Achievement Test (MCAT), Mole Concept Document Analysis Sheet (MCDAS) and Mole Concept Lesson Observation Schedule (MCLOS). The results showed that 62.30% of the variability in students' achievement in chemistry (X11) was accounted for by all the ten predictor variables when taken together. Recommendations based on the importance of these variables were then highlighted particularly the abilities in Spatial and Mathematical abilities.

Keywords: Student Variables, Teacher Variables, School Variables, Mole Concept

Introduction

Dori and Hameiri, 2005 describe chemistry as an 'enabling science' and a 'gate keeper' to many science areas, meaning that performance in lower level chemistry courses grants or denies access to other science areas. Understanding chemistry requires an understanding of concepts around which the discipline is built, such as the Mole Concept that has been described as a threshold concept and an area of troublesome knowledge (Meyer and Land, 2006). Conversely, most high school students have difficulty with the Mole Concept and considerable amount of research has been done on the topic (Zoller, 1990; Nakhleh, 1992; Ayas & Demirbas, 1997; SMASSE, 1998; Coll & Treagust, 2001; Nicoll, 2001; Sheehan, 2010). Since the inception of a new practical-oriented national science curriculum in all Kenyan public schools in 1984, students' overall understanding of scientific concepts seemed to decline each year as evidenced in their performance in national examinations (Waihenya & Siringi, 2001). Preliminary studies conducted by Kenya's Ministry of Education, Science and Technology indicated that students had difficulties learning, among other topics, the "mole concept" (SMASSE, 1998). Many teachers and students noted that the "mole concept" was one of the most difficult topics to teach or learn in school.

The Mole as a 'Threshold Concept'

Ostwald first introduced the concept of the mole in 1890 when he was seeking the chemical formula of 'oxygenated water.' His 'mole' was: *'The normal or molecular weight of a substance expressed in grams.'* Its meaning has since changed and the IUPAC (International Union of Pure and Applied Chemistry) defines the term as:

> SI base unit for the amount of substance (symbol: 'mol'). The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particle. (Furio et al., 2000)

Into the conceptual arena has stepped a new theoretical framework across a wide range of subject areas: *Threshold Concepts and Troublesome Knowledge* (Meyer and Land, 2006, Barradell, 2013). A *Threshold Concept* is a 'core concept', a conceptual 'building block' that leads to progression in understanding of the subject. Meyer and Land (2006) present seven key characteristics of a threshold concept:

Transformative or seismic: once 'got' its effect creates a significant shift in the student view of a subject. Grasping a threshold concept is transformative because it involves an ontological as well as a conceptual shift. We are what we know. New understandings are assimilated into our biography, becoming part of who we are, how we see and how we feel.

Irreversible: once 'got' this different view is unlikely to be unlearned. One of the difficulties teachers have is that of retracing the journey back to their own days of 'innocence', when understandings of threshold concepts escaped them in the early stages of their own learning.

Integrative: Another characteristic of a threshold concept is that it is integrative in that it exposes the hidden interrelatedness of phenomenon. Mastery of a threshold concept often allows the learner to make connections that were hitherto hidden from view.

Bounded: it affects other new concept areas. A threshold concept is likely to be bounded in that 'any conceptual space will have terminal frontiers, bordering with thresholds into new conceptual areas'. One important caution is to be aware that a threshold concept can be a form of disciplinary property and as such, its presentation in a curriculum may carry an inherent tendency to invite congealed understandings. This implies a curriculum design perspective that aims for a research-minded approach to mastery in which there is always space for questioning the concept itself. An essentialist reading of threshold concepts is best resisted by sustaining a sense of their provisional explanatory capacity.

Discursive: Meyer and Land, (2006) suggest that the crossing of a threshold will incorporate an enhanced and extended use of language.

Reconstitutive: "Understanding a threshold concept may entail a shift in learner subjectivity, which is implied through the transformative and discursive aspects already noted. Such reconstitution is, perhaps, more likely to be recognized initially by others, and also to take place over time.

Liminality: Meyer and Land (2006) suggest that learning involves the occupation of a liminal space during the process of mastery of a threshold concept. This space is likened to that which adolescents inhabit: - not yet adults; not quite children. It is an unstable space in which the learner may oscillate between old and emergent understandings just as adolescents often move between adult-like and child-like responses to their transitional status. But once a learner enters this liminal space, she is engaged with the project of mastery unlike the learner who remains in a state of pre-liminality in which understandings are at best vague. The idea that learners enter into a liminal state in their attempts to grasp certain concepts in their subjects presents a powerful way of remembering that learning is both affective and cognitive and that it involves identity shifts which can entail troublesome, unsafe journeys. Meyer and Land (2006) have likened the crossing of the pedagogic threshold to a 'rite of passage' in which a transitional or liminal space has to be traversed; "in short, there is no simple passage in learning from 'easy' to 'difficult'; mastery of a threshold concept often involves messy journeys back, forth and across conceptual terrain.

The Mole as a Potentially Area of Troublesome Knowledge

Troublesome Knowledge is defined as topics, which are major barriers to learning if not understood: students are able to perform mechanical tasks and techniques, yet fail to understand the underlying concepts and the bigger picture. Students typically show behavior such as:

Ritual knowledge: perform superficial tasks and techniques to get a result but fail to understand the complexity that lies behind it.

Inert knowledge: concepts are understood but not actively used or connected to the 'real world' and so there is a failure to see the 'big picture'.

Conceptually difficult and alien knowledge: concepts are found difficult to grasp due to their counter-intuitive or complex nature.

Troublesome language: problems caused by the type of language used during any teaching e.g. a word can have two meanings and phonetic similarity of terms.

Threshold concepts and troublesome knowledge can cause students to become stuck in an 'in-between state' where they oscillate between their own less sophisticated idea and the understanding required by the teacher. The Mole Concept is a very important topic and failure to understand the concept fully causes difficulties in understanding subsequent topics especially stoichiometry problems including volumetric calculations and concentration of solutions. In view of the importance of the mole Concept and the associated difficulties, teachers need a guide on how to teach this topic. Hence there is the need to carry out a study with a view to determining which of the selected variables will have causal relationship with student achievement in chemistry.

Statement of the Problem

The importance of the mole as a threshold concept which pervades all chemistry cannot be overemphasized. Teachers and students appreciate the topic as one of the most difficult to teach and learn in the secondary school chemistry curriculum. With respect to the factors influencing chemistry achievement, no one particular intervention program has received unequivocal support and, therefore, comprehensive approaches to identifying and finding ways of ameliorating differences in chemistry education are needed. Research must therefore focus on the influence of many variables. It is on the basis of this that the study constructed and tested an eight-variable model for providing a causal explanation of secondary school students' achievement in mole concept area of chemistry. Based on the stated problem the study attempts to provide answers to the following questions.

Objectives of the Study

The study aimed at constructing and testing a model for providing causal explanations of secondary school achievements in chemistry on the mole concept in terms of student variables–gender, spatial ability, mathematical ability, socio-economic status, attitude; teacher variables–mode of instruction, teacher attendance of inset, qualification, teaching experience and school variables–resources adequacy.

Based on the objective, the study attempts to provide answers to the following questions:

1. What is the most meaningful causal model for students' achievement in Mole concept area of secondary school chemistry?
2. To what extent will the 11 independent variables when taken together, predict students achievement in mole concept area of chemistry?

Significance of the Study

This study seeks to identify the influence of school, teacher and student related variables as they relate to the chemistry achievement of secondary school students in Kenya on the Mole concept. By examining all the factors in a causal model, it is possible to obtain an insight into the complex network of social and cultural factors that are responsible for the differences observed in chemistry education. In terms of policy making, the study can contribute to the formulation of further educational policy and strategies for the teaching and learning of the mole concept, as well as the ways in which the Kenyan curriculum can best serve the needs of the various students.

Underlying Theoretical Framework

The focus of the study is hinged on teacher and student; therefore, theories that have to do with the characteristics of both of them as they affect learning would be applicable. The study is based on the theory of curriculum modulation and constructivist theoretical framework (Atwater, 1996). One of the supporting structures of this study is the theory of curriculum modulation which envisions the curriculum naturally changing shape and emphasis as it progresses from its intended form, through implementation by the teacher, to enactment in the classroom setting and subsequent learning by students. Each curriculum domain-intended, implemented, enacted and learned- intersects with the next to form a sequence in which instructional materials, teacher and students are major participants and determinants of the curriculum. Therefore, each classroom, as a unique blend of materials and individuals, produces a complex set of factors that influences learning. This study also supports constructivist's view that learners are actively engaged in making meaning and in the construction of ideas. And this could be said to be affected by variables that have to do with them; these student, teacher and school related variables that are considered in the study.

Research Design

A descriptive survey research design was adopted for the study. This was because there was no manipulation of independent variables.

Procedure

The population for the study was made up of all secondary school form three students and their teachers in Kakamega County, Kenya. A total of three hundred and eighty four students were used in the selected schools. All chemistry teachers in the selected schools took part in the study. The five instruments used for data collection were: (a) Mole Concept Achievement Test for Students (MCAT), (b) Mole Concept Students Attitude Scale (MCSAS), (c) Chemistry Teachers' Questionnaire (CTQ), (d) Mole Concept Document Analysis Sheet (MCDAS) and (e) Mole Concept Lesson Observation Schedule (MCLOS). The administration and collection of all the necessary information were done during the normal class periods with the assistance of the chemistry teachers. Two statistical procedures were employed to analyze the data. These were multiple regression and path analysis. The hypothesized causal model was produced through the linear relationships between the sets of variables involved in the study derived from the three factors that were suggested by Black (1964), Duncan (1966), Bryant and Doran (1977). These were temporal order, previous research and sound theory (theoretical grounds). This causal model is presented in figure 1.

Key

X_1 = Teacher attends In-service Workshops
X_2 = Teacher Qualification
X_3 = Teaching Experience X_4 = Math's Ability
X_5 = Resource Adequacy
X_6 = Spatial Ability
X_7 = Attitude towards chemistry
X_8 = Socio economic status
X_9 = Mode of Instruction
X_{10} = Gender

X_{11} = Achievement in Mole Concept

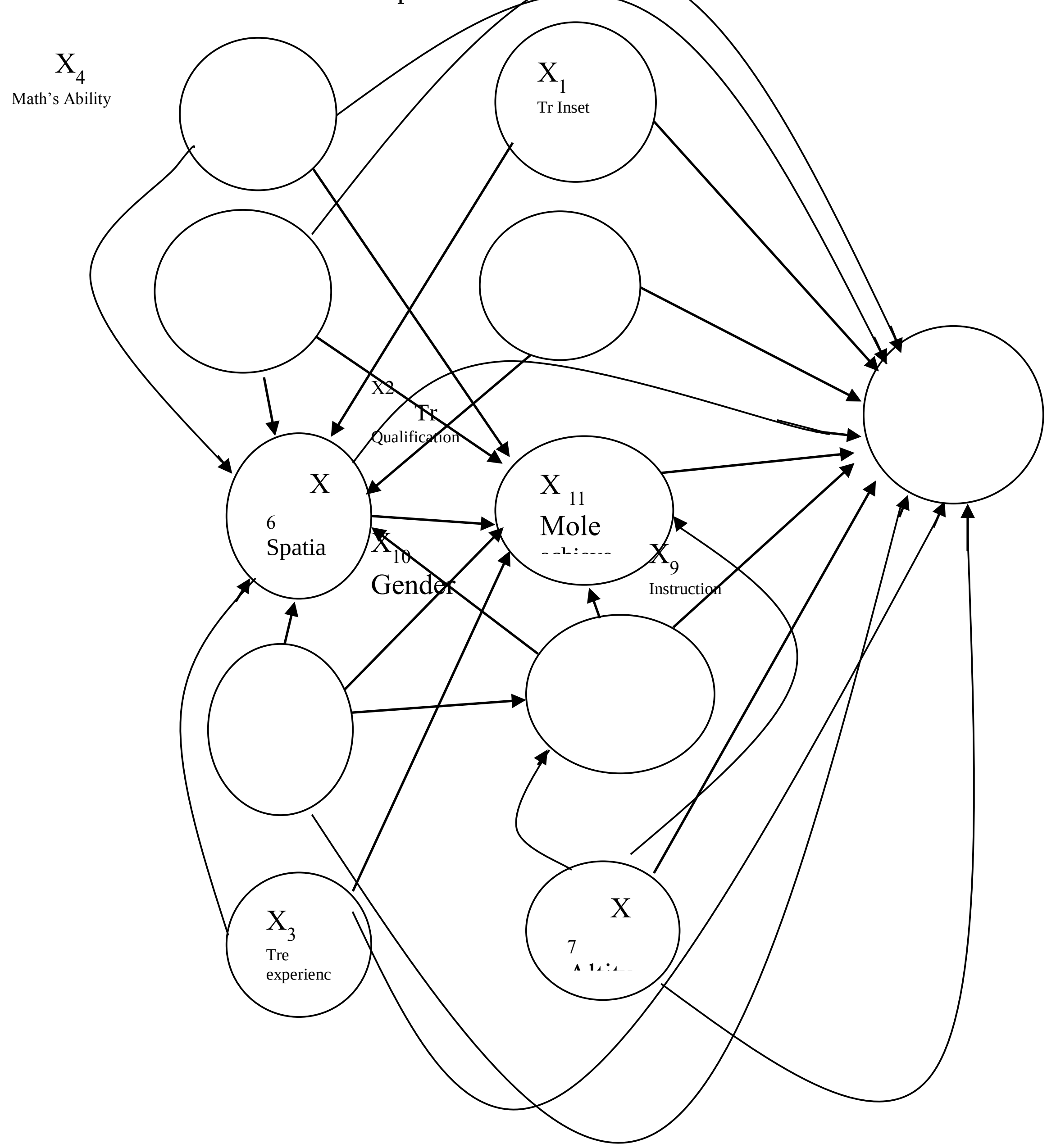

Figure 1: The Hypothesized Model

Hence, the effect of the ten - (10) predictor variables ($X_1 – X_{10}$) on achievement of students in secondary school Mole Concept area of chemistry (X_{11}) was predicted using structural equations which are shown below. In all, the investigators came up with a set of three structural equations after exploring all the hypothetical linkages. The structural equations are labeled (i) - (iii), each equation corresponding to each dependent variable xi (i = 9, 10 and 11)

Structural Equations:

$X_9 = P_{98}X_8 + P_{97}X_7 + P_{96}X_6 + P_{95} X_5 + P_{94}X_4 + P_{93}X_3 + P_{92}X_2 + P_{91}X_1 + e_9$

$X_{10} = P_{109}X_9 + P_{108}X_8 + P_{107}X_7 + P_{106}X_6 + P_{105}X_5 + P_{104}X_4 + X_{103}X_3 + X_{102}X_2 + X_{101}X_1 + e_{10}$

$X_{11} = P_{1110}X_{10} + P_{119}X_9 + P_{118}X_8 + P_{117}X_7 + P_{116}X_6 + P_{115}X_5 + P_{114}X_4 + P_{113}X_3 + P_{112}X_2 + P_{111}X_1 + e_{11}$

To compute values of the path coefficients (associated beta weights) for the hypothesized causal model, three regression analyses were run.

Results

What is the most meaningful causal model for students' achievement in Mole concept area of secondary school chemistry? Table 1 presents the path coefficients and their levels of significance

Table 1: Path Coefficients and their Level of Significance (Significant at p < 0.05)

Paths	**Standard Path Coefficients**
$P_{1, 11}$	-0.11*
$P_{1, 12}$	0.39
$P_{1, 13}$	0.48*
$P_{1, 14}$	0.59*
$P_{1, 15}$	0.42*
$P_{1, 16}$	0.56*
$P_{1 ,17}$	0.51*
$P_{1 ,18}$	-0.47
$P_{1, 19}$	0.45*
$P_{1, 10}$	-0.15
$P_{1, 01}$	0.15
$P_{1, 02}$	0.14
$P_{1, 03}$	0.15
$P_{1, 04}$	0.28*
$P_{1, 05}$	0.26
$P_{1,06}$	0.24*
$P_{1, 07}$	0.23*
$P_{1, 08}$	0.21*
$P_{1, 09}$	0.13
$P_{9, 1}$	0.16*
$P_{9, 2}$	0.18
$P_{9, 3}$	0.21*
$P_{9, 4}$	0.16
$P_{9 ,5}$	0.17*
$P_{9, 6}$	0.16
$P_{9, 7}$	0.14
$P_{9, 8}$	0.13

*Significant at $P < 0.05$

From Table 1, it is clear that fourteen (14) out of twenty-seven hypothesized paths are significant at 0.05 levels. These paths survived the trimming exercise and are therefore represented in the parsimonious model. The paths put together in the model resulted in some pathways through which the independent variables caused variations in students' achievement in chemistry. The twenty-seven pathways hypothesized in the model shown in Figure 1 were reproduced to fourteen significant pathways in Figure 2.

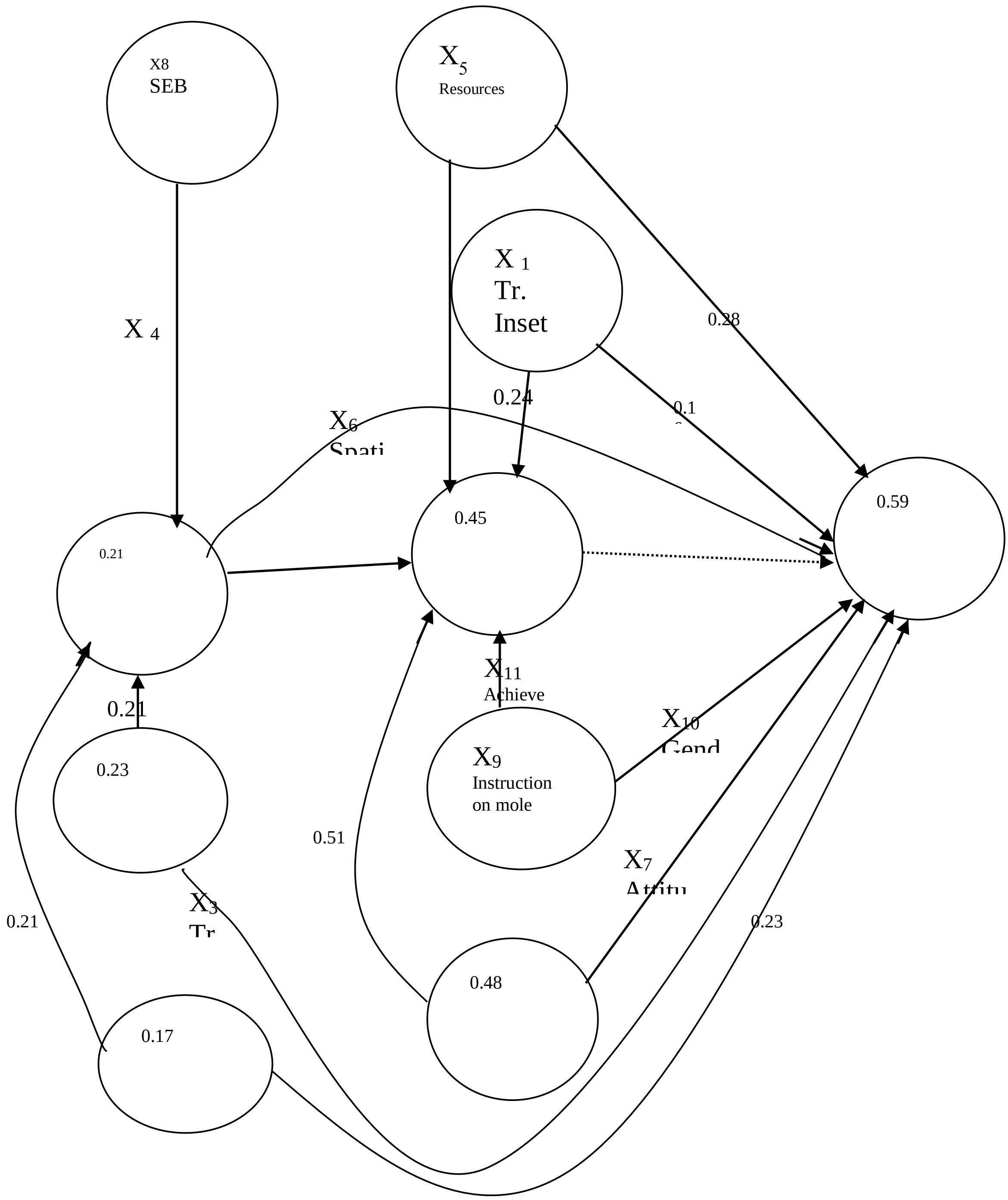

Figure 2: The Parsimonious Model

To what extent will the 11 independent variables when taken together, predict students achievement in mole concept area of chemistry?

Table 2: Composite Effect of the Independent Variables X_I (I = 1, 2, 3 …10) on the Dependent Variable (X_{11})

R	R^2	Adjusted R^2	Standardized error of estimate
.79	.6241	.623	2.5595

In order to determine the most parsimonious causal model R = .79 implies positive multiple correlation among all the ten independent variables and the dependent variable. Adjusted R^2 of 0.623 implies that 62.3% of the total variation in students' achievement was accounted for by the ten independent variables. The remaining 37.7% was either due to error or factors not considered in the study (Table 2).

Discussion

The findings of the study revealed that twenty-seven hypothesized paths were reduced to fourteen significant pathways derived from three structural equations, which were used in explaining the causal model of the student and instructional factors as determinants of achievement in senior secondary school Mole Concept area of chemistry. The efficacy of the new model was verified by reproducing the original matrices of the variables. The original correlation data when verified is consistent with the new model. Hence, the model is retained.

Furthermore, 62.3% of the total variance in students' achievement in chemistry is accounted for by all the ten independent variables when taken together. This figure is very significant in the sense that there are many variables that can cause variance in students' learning outcomes. For the selected ten independent variables among many others, to have accounted for 62.3% of the total variance in the students' academic achievement implies that those ten variables should be given much attention in the teaching and learning of chemistry. The remaining difference (37.7%) in the variance might be due to the influence of other factors not considered in this study.

In addition, only seven variables, Teacher attendance at chemistry workshop (Var. 1) (=-.11), Teaching experience (Var. 3) (= .48), mathematics ability (Var. 4) (= .59), Resources (Var. 5) (= .42), spatial ability (Var. 6) (= .56), Attitude (Var. 7) (= .51) and Mode of instruction (Var. 9) (=.45) have direct causal influences on students' achievement in the Mole Concept area of chemistry. Of the seven variables, mathematical ability (Var. 4) has the highest contribution to students' achievement in chemistry through spatial ability (Var. 6) and students' attitude to chemistry teaching (Var. 7). The finding is in agreement with Adesoji (2008) and Sheehan (2010) who found that mathematical and spatial abilities produced a significant difference in the performance of students in chemistry and by extension to the Mole Concept. Teacher's experience (Var. 3) was also found to significantly affect student achievement. This finding supports the works of Osokoya (1999) who had independently showed that teacher experience predicts students' academic achievement. The reason for this could be explained in the opinion of Hansen (1988) that teachers who have spent more time studying and teaching are more effective. However, this finding is contrary to the work of Adeniji (1999) who found that teacher's length of teaching and administrative experience were not related to students' achievement in science.

A further look at the results of this study shows that variables 9 and 5 (mode of instruction and resource adequacy) also have direct causal influences on students' achievement in chemistry. The findings corroborate those of Wisconsin et al. (1991), Okegbile (1996). The interpretation of this result is that a well-equipped laboratory and availability of textbooks can positively change students' attitude to chemistry teaching, which will in turn enhance students' learning outcomes in chemistry (Var. 11).

Furthermore, the study revealed that other variables like student gender (X_{10}), socioeconomic status (X_8) and teacher qualification (X_2) had very little direct effect on academic achievement in chemistry. Some scholars found student gender to significantly affect achievement in favor of boys (Joseph 1996) while some were in favor of girls (Toh, 1993). Others like, Lagowski (1994) did not see any relationship between student gender and academic achievement. The results of this study did not imply that student gender, socioeconomic status and teacher qualification do not influence achievement at all but in the presence of important factors like mathematical ability, spatial ability, attitude and teaching experience, their effects would be so low that they are not likely to be statistically significant.

Recommendations

After testing of the hypothesized causal model for Mole Concept achievement, the research found that teaching with more emphasis on developing mathematical and spatial cognitive skills is likely to lead to higher motivational orientation and subsequently help learners understand the underlying sub concepts. Therefore, the cognitive ability of students at all levels in the Kenyan classrooms needs to be taken into account. It should not be assumed. Results from this investigation indicate that the cognitive ability of students is central to their understanding and performance on the Mole Concept. Teaching strategies therefore need to take account of the actual cognitive abilities of students and seek to develop their high order cognitive skills.

References

Atwater, M. (1996). Social Constructivism infusion into the Multicultural Science Education Research Agenda. *Journal of research in Science Teaching,* 38, (8), 871-889.

Ayas, A. & Demirbas, A., (1997). Turkish Secondary Students' Conception of Introductory Chemistry Concepts, *Journal of Chemical Education*, 74(5), 518-521.

Adeniji, I. A. 1999. A Path Analytic Study of Some Teacher Characteristics and Teacher Job Performance in Secondary School in Ogun State, Nigeria. Unpublished Ph. D Thesis, University of Ibadan, Ibadan.

Adesoji, F. & Olatuhbosun, S., (2008). Student, Teacher and School environment Factors as Determinants of Achievement in Senior Secondary School Chemistry in Oyo state, Nigeria. *Journal of International Social Research*. 12 (1), 123-140.

Barradell, S. (2013) *The identification of threshold concepts: a review of theoretical complexities and methodological challenges*, Higher Education, 65 (2), 265-276.

Black, H. M.(1964) *Causal Inferences in Non–Experimental Research*. Chapel Hill, University of North Caroline Press.

Dori, Y. J & Hameiri, M. (2003). Multi-dimensional Analysis System for Quantitative Chemistry Problems: Symbol, Macro, Micro and Process Aspect. *Journal of Research in Science Teaching,* 40 (3), 278-302.

Furio C., Azcona R. & Guisasola J. & Ratcliffe M. (2000). Difficulties in Teaching the Concepts of 'Amount of Substance' and 'Mole', *International Journal of Science Education* 22, 1285-1304.

Joseph, E. U. 1996. Gender Differences in Senior Secondary School Chemistry Performance in Akwa – Ibom State. In E. N. Okpara (ed) Gender Issues in Education and Development. A Book of Readings 8: 189-195.

Lagowski, J. I. 1994. Chemistry Problem – Solving Abilities, Gender, Reasoning Level and Computer Simulated Experiments. Paper Presented at the Annual Meeting of the National Association for Research in Science Teaching. Anaheim, C. A., 26-29.

Meyer, F. J., & Land, R. (2006). Overcoming Barriers to Student Understanding: threshold concepts and troublesome knowledge. Routledge-Taylor & Francis Group. London and New York.

Nakhleh,M., (1992). Why Some Students Don't Learn Chemistry: Chemical Misconceptions, *Journal of Chemical Education,* 70(3), 190-192.

Nicoll, G., (2001). A report of Undergraduates' Bonding Alternative Conceptions, *International Journal of Science Education,* 23 (7), 707-730.

Okegbile, S. O. (1996): *Evaluation of Practical Lessons in Science.* Being a paper presented at the Managerial Conference of School of Science Education at the Federal College of Education, Osiele, Abeokuta. 7th -9th May.

Osokoya, M. M. (1999). *Some Determinants of Secondary School Students' Academic Achievement in Chemistry in Oyo State*. Unpublished Ph.D. Thesis, University of Ibadan, Ibadan.

Sheehan, M. (2010). Identification of Difficult Topics in the Teaching and Learning of Chemistry in Irish Schools and the Development of an Intervention Programme to Target some of these Difficulties. UL. PhD thesis.

SMASSE Project 1998 (nd) *Strengthening Mathematics and science in Secondary Education project*: Ministry of Education Science and Technology, Republic of Kenya. [On-line]. Available: http://www.smasse.org

Toh, K. A. 1993. Gender and Practical Tasks. *Science Education Research* 35: 225-265.

Waihenya, K., & Siringi, S. (2001, October 08). Study time: A new report attributes the poor performance in national examinations to inadequate preparation and failure to read questions carefully. Daily Nation. [On-line]. Available: http://www.nationaudio.com/News/DailyNation/Today/

Wisconsin T. Allen & Herlming (1991). *Student/Teacher Ratio.* Tennessee K-3 Class size Study. Mask Ville Tennessee State Department of Education.