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Abstract

Purpose: A critical question addressed in this paper concernsthe casual linkage of Ordinary-Level subjects to promote science academic performance. We develop a structural equation model to determine the contribution of vocational, social science and language subjects to students' grades in mathematics and subsequently science subjects.

Methodology: The paper uses secondary data from the Uganda National Examinations Board (UNEB) for the year 2014.

Findings: The results of structural equation modeling demonstrate that grades obtained in social science and vocational subjects negatively contribute to the grades obtained in mathematics and this effect was significant at 1 and 5 percent level respectively. In contrast, thepath for the latent variable Language show that high academic achievement in Language subjects is positively and significantly ($p<.01$) related with performance in mathematics. It was also established that grades obtained in mathematics positively significantly ($p<.01$) impact on the grades obtained in Science related subjects.

Policy Recommendation: We recommend that students wishing to specialize in science related disciplines must be informed about the core subjects that enhance their likelihood of understanding science. Going by the findings, teachers should always emphasize the importance of language in developing students' competency in mathematics which also significantly impacts academic achievement in science.

Key Words: *causal linkage, academic performance, skill-gap, science*

1.0 Background

Globally, education is considered a panacea through which economic growth and human capital development can be attained. Because of its role in society transformation, the quality of knowledge and skills provided to learners are increasingly becoming a pre-requisite for the entry into the workforce (Wheelahan, Buchanan & Serena, 2015). For this reason, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) stipulates that education is a channel through which learners can be empowered to become active participants in the transformation of their societies (UNESCO Social and Human Sciences, 2009). Given this role, education institutions are increasingly challenged to provide academic disciplines that will equip students with employability skills in order to respond to the changing and complex needs of the job market. These disciplines are typically divided into four branches namely: social sciences, humanities, natural sciences and formal sciences (Wikipedia.org). This division as Sloan (2008) reveals, is only a few centuries ago where all sciences were branches of philosophy, which today is regarded as part of the humanities.

The aim of the paper is to explore the causal linkage of Ordinary-Level (senior-four) subjects to promote science academic performance for bridging the skills-gap in Uganda. In particular, the paper sets out to develop a Structural Equation Model (SEM) of Ordinary-Level subjectrelationships in the following academic disciplines as laid down by the National Curriculum Development Centre (NCDC, 2016): (a) science (b) math (c) languages (d) social sciences and (e) vocational subjects. The overall object of the SEM is to establish that a model derived from theory has a close fit to the sample data in terms of the difference between the sample and model-predicted covariance matrices.

The assumption of this paper is that a causal linkage between subjects in say languages can enhance performance in science disciplines. In other words, the paper sought to determine whether proficiency in languages, social sciences and vocational subjects are essential precursors to students' success in mathematics and subsequently science being advocated for in the modern society. This importance is well summarized by Linus Pauling (1951 cited by Shawn et al. 2006) who made a compelling statement that science has played a major part in determining the nature of the modern world, the food we eat, the clothes we wear, the means of transportation, the medicines, and the weapons for security. He therefore recommends a program of education where each student must have knowledge of science. This requirement is intended to ensure that in addition to preparing specialists in science who will serve as the next generation of scientists, it's important to prepare scientifically literate non science students who can think scientifically in their respective fields (American Association of Colleges and Universities, 2006).

The realization of the general concern that insufficient student skills in science related subjects is one of the factors that have led to shortages of key competencies regarding rapid technological changeled Uganda to launch a strategic government policy on science education (Tinkamanyire, 2010). The aim was to bridge the skills-gap by training more scientists. The policy, which took effect in 2006, made the study of science subjects, namely: Physics, Chemistry, Biology and Mathematics compulsory for Ordinary-Level secondary school students.

Cross-country studies suggest that aggregate measures of test scores in subjects such as mathematics and science are important determinants of economic growth. One of such studies is that of Maria, Vera and Francisco (2012) who argued that proficiency in languages, science, and mathematics is an essential precursor to success in modern society. This underscores the notion that development of a modern civilization has a lot to do with advancement in science. But despite its potential role in enhancing development as highlighted by the Government White Paper on Education (1992), Uganda's education curriculum has hitherto largely promoted humanities subjects, producing large numbers of graduates meant to work in offices. Consequently, high unemployment rates in Uganda are attributed to the poor education system that has existed for more than 50 years.

The system has been regarded as elitist, less practical, academic-oriented, and not skills-driven. As such, serious concerns have been expressed about an increasingly wide gap between the skills and capabilities of graduates who have either less or no practical significance to the requirements and demands of the labour market. Anecdotal evidence suggests that many of these students are poorly motivated, do not see the relevance of science to their careers, and find science frustratingly difficult (Arwood, 2004). This negative attitude towards science has provoked the concern that future society would lack scientists. Policymakers, education researchers, and science teachers have regarded this latent threat as the most imperative, because the era of science calls for more scientific knowledge which, in turn, supports economic development (Jenkins & Nelson, 2005).

2.0 Theoretical structural model

Some studies in science education have tried to analyze the causal relationships between certain variables on student performance in science. To the researcher's knowledge however, no empirical confirmatory model in the current literature has been fully established or extended to estimate the causal linkage of subjects to promote science academic performance for bridging the skills-gap to promote economic growth in Uganda. The paper therefore aims at determining the causal relationships by determining the Ordinary-Level subjects that have a potential of promoting science performance.

We used the available theoretical and empirical findings to hypothesize one of the potential structural models of performance in science related disciplines. The hypothesized model included nine observed and five latent variables (figure 1). The assumption was that three of the five latent variables (vocational, social science and language subjects) were core in learning mathematics and were therefore treated as exogenous. In the same line, the latent variable Mathematics was treated as an exogenous variable in explaining the grades obtained in science disciplines.

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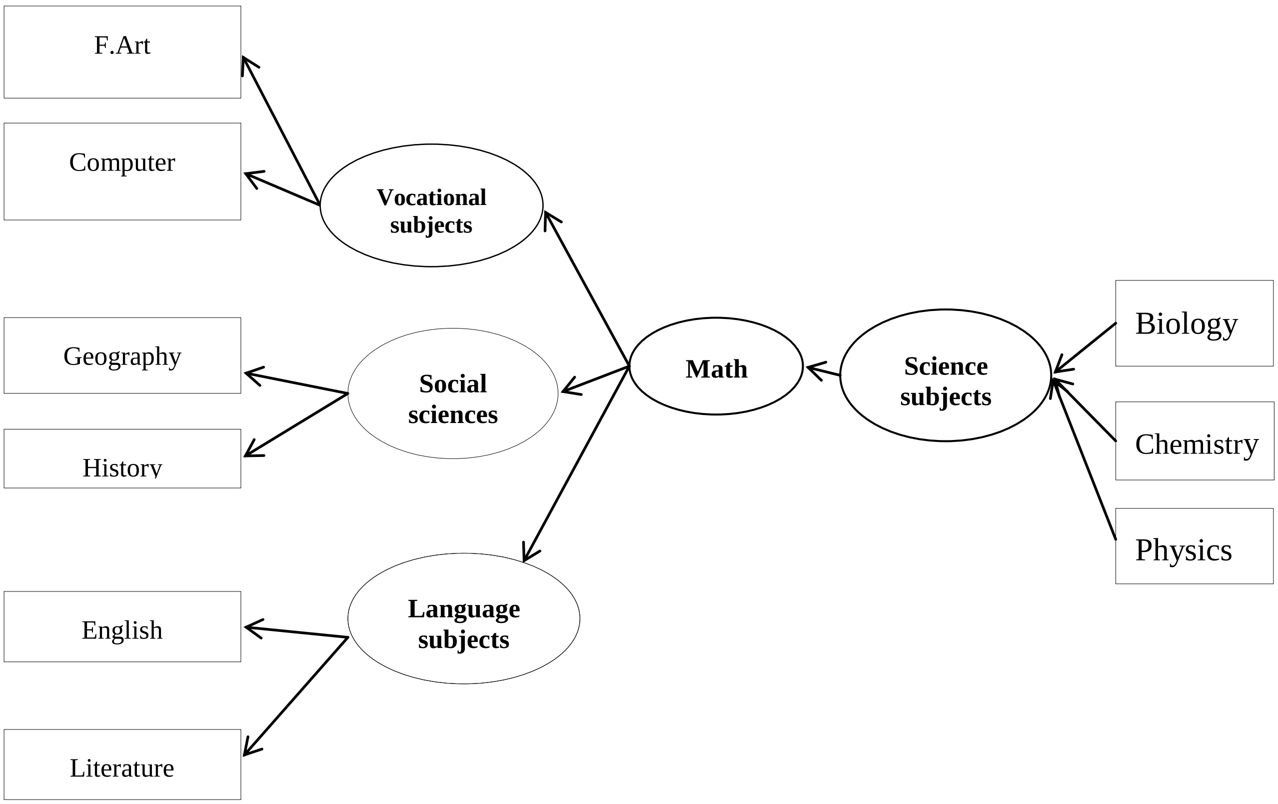


Fig 1: Model for the causal linkage of Ordinary-Level subjects to promote science performance

In the structural model described in figure 1, it was assumed that grades obtained in vocational, social sciences and languages related subjects significantly impact on students' achievement in mathematics while high achievement in mathematics would enhance the grades obtained in science. It was thus assumed that the grades obtained in mathematics are significantly dependent on each of the three latent variables. According to the theorized model, high grades in mathematics positively affect science performance and vice versa. That is, a student who obtains low grades in mathematics is also less likely to obtain high grades in science related subjects.

2.1 Related Literature

To promote student's performance in science, several international researchers have carried out quantitative assessments of the determinants of students' performance in science subjects. These studies have tried to analyze the causal relationship of variables on student performance with some papers analyzing the impact of test scores on individual outcomes or predicting future employment and earnings among others. This section reviews some studies that have used SEM to explore the causal relationship between different parameters to predict students' academic outcomes.

Maria, Vera and Francisco (2012) conducted a study to determine how different but interrelated variables could lead to an explanation of student attitudes towards math. The hierarchical analysis using SEM showed that motivation-related variables are the main predictors of attitudes towards mathematics. Another strand of the literature used SEM to investigate students' career awareness in Science and according to the results of Oksana, Alves and Bahry (2012), it was discovered that for both the USA and Canada, students' self–efficacy in science had the largest direct effect on their science proficiency. In their analysis, Minkee and Jinwoong's (2010) findings revealed that students' intrinsic attitude to science stimulates their school achievement. Subject–related enjoyment has also been reported to influence students' academic motivation, performance, course selection, and career pursuits. In particular, subject–related enjoyment and interest have been found to have positive effects on performance outcomes (Lepper& Cordova, 1992 cited by Oksana *et al.*, 2012). In a more recent study that investigated the causal relationship of variables of self-efficacy, mathematics self-concept and attitude towards mathematics with academic achievement in mathematics and mediation of approaches to learning in high school students in Gerash City, the SEM results of Jamaldini *et al.* (2015) indicated that all direct and indirect paths (effects) in the model were significant. In the same line, the complexity of variables that have a potential impact on math performance was proved by Singh, Granville, and Dika (2002) when they found out that high achievement in mathematics is a function of many interrelated variables related to students, families, and schools. In addition, Mato and De La Torre (2010) quoted by Maria *et al.* (2012) discovered that students with better academic performance have more positive attitudes regarding math than those with poorer academic performance.

One important observation that can be made from the above review is that although some attempt has been made to examine the causal relationship between variables to predict students' academic outcomes, no integral research has been done to investigate the link between academic disciplines at Ordinary-Level and their combined effects to promote science academic performance in Uganda. This paper is therefore different from other studies in that we examined the causal linkage by determining the Ordinary-Level subjects that have a potential of promoting science performance. The basic premise on which this paper is based is that Ordinary-Level students with higher scores in social science subjects (i.e. Geography, History), vocational subjects (i.e. Computer and Fine Art) and languages (i.e. English Language, Literature in English) could achieve better in math and science subjects (i.e. Biology, Chemistry and Physics). The experimental setting that the paper exploited aimed at providing evidence of the important subjects at Ordinary-Level that enhance students' proficiency in mathematics and consequently achievement in science subjects.

3.0 Methodology

The analysis presented in this paper uses secondary data from the Uganda National Examinations Board (UNEB) for a sample of 65,535 students who sat the Ordinary-Level exams for the year 2014. The sample was slightly skewed in favour of male candidates (53.4%) with a mean age of 18 years and a standard deviation of 1.74. According to the UNEB ranking, each student receives a score depending on his/her performance which range from zero to 100%. These scores are then graded with D1 indicating higher scores while F9 signifies low scores. The grades obtained in the final exams were used as a measure of students' achievement in the subjects indicated in the theoretical model. In analyzing the data, a descriptive analysis was conducted to examinecharacteristics of the data of the average grades obtained in each of the ten (10) Ordinary-Level subjects considered in this paper. Then a pairwise correlation coefficient was employed to determine the relationship between the grades obtained from one individual subject against another or other subjects. Finally, the data was analyzed using structural equation modeling.

4.0 Results

This section contains the descriptive statistics (mean and standard deviations) of the variables used in the analysis. Secondly, correlation coefficients for every variable were used to identify the relationships between the subjects indicated in the theoretical model. Consistent with the theoretical model presented, a Structural Equation Modeling analysis was performed to calculate the coefficients in order to test a causal linkage of subjects. This was done using STATA 13. The following table summarizes the grades obtained in the 2014 National examinations for the subjects considered in this study.

Table 1: Descriptive statistics of grades

Variable	Mean	Std. Dev.	Min	Max
Fine Art	6.37	2.02	1	9
Computer	5.75	2.26	1	9
History	6.00	2.44	1	9
Geography	6.73	2.25	1	9
English	5.99	2.26	1	9
Literature	5.85	2.25	1	9
Math	6.54	2.28	1	9
Physics	6.82	2.13	1	9
Chemistry	7.65	1.89	1	9
Biology	7.42	1.91	1	9

The average grades summarized in Table 1 show that the best done subjects included computer (Mean=5.75, Std=2.26), literature in English with an average of 5.85 (std=2.25), English (mean=5.99, std=2.26) and History (mean=6.00, std=2.44). This shows that in the above-mentioned subjects, most students obtained credit six (C6) according to the grading system used by UNEB. As has been the general trend over the years, science related subjects were the worst done. In the table, chemistry (mean=7.65, Std=1.89), biology (mean=7.42, std=1.91) and physics (mean=6.82, std=2.13) were the worst done subjects respectively. In these subjects, the average grades obtained translate into pass seven or eight. In order to determine whether a correlation exists between the different subjects, a Pearson correlation coefficient was run to determine this relationship. For the purpose of this paper the grades obtained by each student were reverse coded on a scale of 1-9 so that higher ranks on the scale indicated better performance and vice versa. Table 2 presents a summary of the findings.

Table 2: Correlation coefficients between the grades obtained in different subjects

	F.Art	Computer	Hist	Geog	Eng	Lit	Math	Phy	Chem	Bio
F.Art	1									
Computer	0.43*	1.00								
Hist	0.51*	0.59*	1.00							
Geog	0.54*	0.57*	0.63*	1.00						
Eng	0.54*	0.54*	0.69*	0.66*	1.00					
Lit	0.55*	0.55*	0.69*	0.63*	0.68*	1.00				
Math	0.53*	0.53*	0.61*	0.59*	0.61*	0.61	1.00			
Phy	0.45*	0.61*	0.70*	0.63	0.62*	0.62	0.57*	1.00		
Chem	0.56*	0.55*	0.65*	0.69*	0.65*	0.63*	0.72*	0.69*	1.00	
Bio	0.67*	0.56*	0.59*	0.63*	0.62*	0.62*	0.65*	0.59*	0.77*	1.00

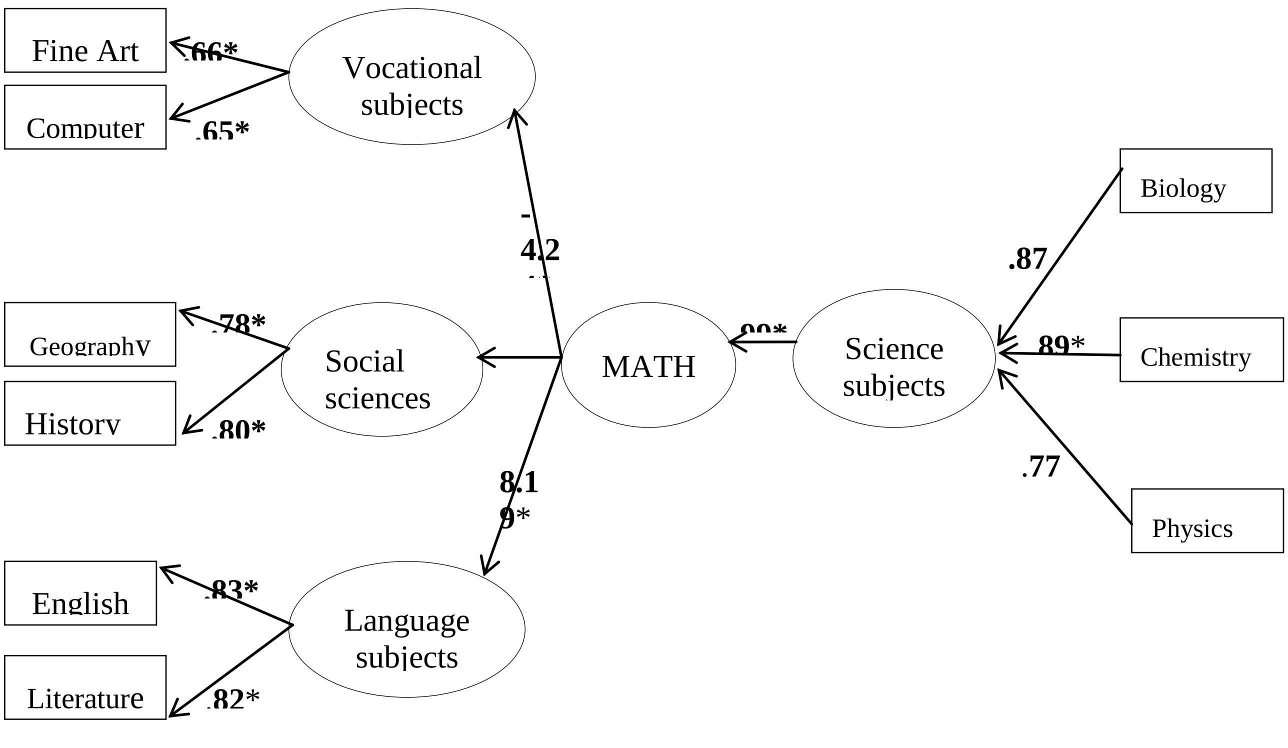
* Significant at 1 percent level

Table 2 reports the correlation coefficients between the subjects explored in this paper and according to the findings, all correlations are positive and significant at 1 percent level. This shows that candidates with good grades in one subject were also likely to have better grades in another or other subjects. Despite carrying positive coefficients, the subjects that have the highest linear relationship included biology and chemistry ($r=0.77$, $p<0.01$), mathematics and chemistry ($r=0.72$, $p<0.01$). This means that a student with good grades in one of the above subjects was also likely to have good grades in the corresponding subject. Among the Vocational subjects, computer correlates more with Physics ($r=0.61$, $p<0.01$) while Fine Art correlated more with biology ($r=0.67$. $p<.01$). For social science subjects, history correlates more with other subjects compared to geography, the same relationship holds for languages where the grades obtained in English had the highest connection with other subjects compared to literature. Lastly, a look at the correlation coefficient for science subjects show that chemistry and biology on average correlate more with other subjects compared to physics. These results were later substantiated with the values of the standardized estimates in the structural equation model in Figure 2.

4.1 Results of the model

Structural equations modeling tested the overall model fit of vocational, social sciences, languages, math and subsequently grades obtained in science subjects. Statistical measures of fit included the Chi-square ($\chi 2$), Comparative Fit Index (CFI) which determines whether the hypothesized model is a better fit to the data than a null model and the values range from 0 to 1; and the Root Mean Square Error of Approximation (RMSEA) which assesses the degree of complexity in the model, and resulting values close to 0.06 indicate adequate model-data fit (Hu and Bentler 1999). A non-significant $\chi 2$ suggests that the model fits the data adequately, but $\chi 2$ is sensitive to sample size. In this paper, goodness of fit statistics were confirmed with a maximum likelihood ratio $\chi 2$ of 377319.017, with a p-value of 0.000 with a Root mean squared error of approximation, RMSEA of 0.117, Comparative fit index (CFI) of 0.948, Tucker-Lewis index OF 0.917 and Coefficient of determination (CD) of 0.519 which means that the model explains 51.9 percent of the variance to grades in science. Figure 2 reports the results of the structural equation model.

Figure 2: Structural equation model and significant standardized estimates



* Significant at 1 percent level **Significant at 5

The standardized factor loading for Fine Art and Computer onto the latent variable vocational subjects were 0.66 and 0.65 respectively with an equal value of standard errors equal to .003 and significant at p < .001. Fine Art is therefore the major subject that loads significantly highly on the latent variable Vocational subjects. In the same Figure, we see a significantly (p<.05) positive path between geography and history on the latent construct Social sciences. Since history has the highest value of the standardized estimate, this means that compared to geography, history has a major contribution in explaining the grades obtained in social science subjects. Turning to languages (English and Literature), the standardized estimates for each of the two subjects were positive and highly significant at 1 percent level, with English having the highest role in explaining the grades obtained in Language related subjects.

In the same Figure, two paths carry negative signs to indicate that higher grades obtained in vocational and social science subjects significantly reduces the grades obtained in mathematics with vocational subjects having the greatest negative effect (-4.24). Regarding the inverse relationship between vocational subjects and achievement in mathematics, the findings are supportive of the results of Alexander, McCormick and Houser (1995) who analysed the relationship between vocational course taking and academic achievement as measured by the 1990 National Assessment of Educational Progress (NAEP). Analysis of the data showed a consistent inverse relationship between vocational course taking and NAEP assessment scores. The researchers however, stress that despite the inverse relationship, this cannot be taken as evidence that increased vocational course taking depresses achievement. Rather, it might be found that students who generally score lower on tests also tend to take vocational courses, or that students who take vocational courses miss the courses that may help increase test scores.

In contrast, the positive and significant path for the latent variable Language show that high academic achievement in Language subjects is positively (.82) and significantly ($p<.01$) related with performance in mathematics. This shows that students' knowledge in Language subjects as well as their knowledge of mathematics significantly improves their performance in science related disciplines. The findings suggest that students who experience difficulties in the three language skills namely reading, writing and listening may not effectively function in science related subjects. This is because in many Common Wealth countries Uganda inclusive, English is the language of textbooks in schools. This therefore suggests that students must understand clearly the connection between language subjects and mathematics in order to be able to improve their grades in science subjects.

Regarding the effect of math grades on science performance, we see a positive and significant path ($p<.01$) which means that grades obtained in mathematics positively impact on the grades obtained in Science related subjects. The results of the model further show chemistry as the subject with the largest standardized estimate (.89) an indication that Mathematics is an essential skill for chemistry students to master. This is followed by the standardized coefficient for biology (.87) while physics has the lowest standard estimate (.77). The outcomes of this analysis have also been documented by Karen and Lenora who reviewed related empirical studies regarding the correlation between math ability and success in a high school chemistry course. The findings of their review demonstrated a direct correlation between a student's math skills and success in college chemistry courses. Similarly, in Denny's (1971) study of chemistry textbooks copyrighted from 1960 to 1970, ten math skills were found in all the texts for solving chemistry problems. The findings further corroborate Mupanduki's (2009) study in which it was established that chemistry students enrolled in the integrated chemistry and mathematics (Integrated CHEMAT) program scored significantly higher than their counterparts enrolled in the traditional, block-schedule chemistry (Regular CHEM) program. On this note, Grove and Pugh (2015) have pointed out that while there appears to be a tendency for chemistry departments to consider mathematics a 'physical chemistry issue', the findings in this paper indicated that a range of mathematical skills are required for one to obtain good grades in chemistry. Malkevitch (2014) emphasizes this assertion by stating that mathematics has produced more tools for chemists to put to use just like the chemists have done so. From the very beginnings of chemistry, mathematics was used to create quantitative and qualitative models for helping comprehend the world of chemistry by understanding the elements that make up molecules. For example, chemists use group theory to study aspects of their field, but this as a mathematical tool came much later than the first work that made chemistry more "mathematical."

Also, since a basic knowledge of mathematics was a precursor for understanding biology, the findings show that Biology is changing and becoming more quantitative. For this reason, Karzai and Kampis (2010) urge teachers to develop students' capacity for critical thinking and problem solving. Indeed, including biological data and biology-loaded topics in math courses and quantitative training in biology courses has become a successful recent development. We are now starting to understand that the amazing complexity and diversity of living organisms commonly stems from ultimately simple rules that can be explored by computational and mathematical means (Kauffman, 1993). In view of the high intimacy between math and biology, the National Research Council (quoted by the National Academies Press. 2003) issued a report that suggested that biology should become more quantitative. In response to this call, studies done elsewhere show that biological researchers and educators are now closely collaborating with mathematicians and scientists from other fields *(*Uhden, *et al.,* 2011).

Generally considered a relationship of great intimacy, Bailly and Longo (2011) describes mathematics as an essential tool for physics. Similarly, Sanjay and Dilip, (2012) describe physicsas a rich source of inspiration and insight in mathematics. In fact, Mazer (2011) reveals that from the seventeenth century, many of the most important advances in mathematics appeared motivated by the study of physics, and this continued in the following centuries. The creation and development of calculus were strongly linked to the needs of physics: At that time just like today, there was a need for a new mathematical language to deal with the new dynamics that had arisen from the work of scholars such as Galileo Galilei and Isaac Newton (Newton, 1997). During this period there was little distinction between physics and mathematics; before giving a mathematical proof for the formula for the volume of a sphere, Archimedes used physical reasoning to discover the balancing of bodies on a scale. All these validate Nikitina and Mansilla’s (2003) assertion that thinking about science and mathematics means thinking in terms of unifying mathematical constructs or scientific ideas that have the potential to produce sharable tools and understandings.

5.0 Conclusion

Although the relationships among O-Level subjects and overall underlying achievement in science related disciplines has not been fully established in the literature especially in Uganda, this paper has provided evidence that mastery of English plays a pivotal role in enhancing students’ proficiency in mathematics and consequently achievement in science subjects. The fact that mathematics enters at every stage of science is an indication that without mathematics, we cannot effectively talk of Uganda’s educationperformance issues, environmental concerns, technological advancement, and economic competitiveness especially at a time where most current real-world situations present diverse problems that are multidisciplinary in nature and require multidisciplinary attention and solutions. Accordingly, an essential ingredient for students' success in science will highly depend on their ability to tap into diversity and make connections between school subjects, incorporate information from different subjects to solve scientific problems. As a possible alternative to traditional teaching and learning methods, curriculum integration presents a very viable route towards reform and better student academic outcomes. The outcomes of this paper thus pave the way towards our understanding of the steps which policy makers in the education sector need to take in order to improve students' performance in science education. The paper makes recommendations which can be considered in their quest for promoting students' success in science subjects to increase science-courses enrolment for the skills gap.

First, the importance of language in developing students' competency in mathematics and science should be emphasized. There should be continual opportunities for students to apply and develop their literacy and numeracy skills. In doing so, staff need to clarify why English (the medium of instruction) and mathematical techniques are important in someone's life. Secondly, students wishing to specialize in science related disciplines must be informed about the core subjects that enhance their likelihood of understanding science. Critical to this endeavor is the need for teachers to construct a form of practice that fits with their students' ways of learning and how to harmonize their teaching methods to enhance students' competency in science subjects. This would however require systemic reforms in the way teachers are prepared, certified, and assessed. Finally, key mathematical ideas, concepts and results should not be hidden from students, but should be presented in ways that they can understand and appreciate.

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