Stem Integration Model for Secondary Education in Kenya

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Abstract

Academic instruction has commonly adopted the approach of instruction of single disciplines. This has limited learners from making connections within, between and among disciplines. The result is that students do not apply knowledge and skills learnt in one topic to another in the same discipline or to another discipline. This has been evidenced in national examinations in Kenya. This paper proposes a classroom integration model for Science, Technology, Engineering, and Mathematics (STEM). A qualitative research approach was used. The target population was all secondary school learners within three centers purposefully selected. Data was collected through observation, group discussions and document analysis. The learners engaged with connecting mathematics content within and across grade levels and document analysis of conceptual connection between chemistry and mathematics was done. Findings show that learners identified connections within and across grade levels, however, some topics were not connected. The mathematics concepts tested in chemistry made it difficult for some learners to correctly respond to the questions. To realize improvement, a model for STEM integration is proposed to facilitate cross-cutting understanding and application of concepts which can be translated to industries, projects, and everyday life. Further research on the model and on integration in general, is recommended.

***Keywords*: Discipline Integration, STEM Integrated Curriculum, Classroom Instructional Model, STEM Education**

Introduction

The potential of Science, Technology, Engineering, and Mathematics (STEM) education can be realized by refining the pedagogical approaches of the disciplines. One approach is to integrate the instruction of the disciplines to supplement the traditional methods of instruction in isolation. Integration has been implemented in different contexts using different approaches and models such as individual disciplines, multidisciplinary, interdisciplinary and trans-disciplinary or a combination of them (Drake, 1998; Lederman & Neiss, 1997), and a continuum of integration using a 10 step model (Forgarty, 1991). The approaches are generally seen to allow students to make real-world connections with the knowledge, skills, values and attitudes learned in class and prepare for STEM learning pathways and careers. Key in integration is to develop relevance and explore application of the disciplines to the existing student experiences and solve real world problems.

Rationale For Integration

Discipline integration is an effective instructional approach because basic qualities of cognitive, psychomotor and affective domains favor connected concepts more than otherwise since they are better organized for future retrieval, use and meaning making. The connected knowledge structures can support learners' ability to transfer knowledge, skills, values and attitudes to new or unfamiliar situations. Furthermore, being able to represent a concept within and across disciplines in multiple ways has the potential to facilitate and improve learning. Arguments on the need for integration have been put forward, for example, mathematics and science embrace similar attempts to identify patterns and relationships, and they share scientific processes such as inquiry and problem solving (American Association for the advancement of Science (AAAS), 1993). Researchers, therefore, suggest that in learning, disciplines should be connected to real-life situations so that students learn and appreciate how different disciplines can be used together to solve real world problems (Beane, 1995) by engineering designs and using technology as a tool. In the current times, integration of STEM disciplines is necessary and a deliberate attempt to train and develop personnel for industrialization, knowledge-based economy and to develop 21st Century skills, especially in technology and its use world over (Bybee, 2010). The expected outcomes in STEM integration (English, 2016) includes recognizing and applying concepts that have different meanings or applications across disciplinary contexts, solving problems, creating knowledge, recognizing when a concept or practice is presented in an integrated way; and drawing on disciplinary knowledge to support integrated learning experiences and knowing when to do so. In light of Kenya's context, integration has the potential for realization of industrial needs and in everyday life as envisaged in Vision 2030.

The objectives of this study are to:

1. Identify and review the existing models of STEM integration in different contexts and
2. Propose a model for STEM integration in Kenya.

Review Of Literature

In the USA, some states have integrated STEM disciplines in their curriculum and their governments continue to allocate funds for the same (Bybee, 2010). Africa has generally lagged behind the rest of the world in its capabilities for STEM education and integration since it generally lacks educational infrastructure associated with STEM education, limited allocation of funds and minimal attempt at integration. However, it is envisaged in the African Union's Agenda 2063 of transforming Africa to be a continent where "well educated and skilled citizens, underpinned by science, technology, and innovation for a knowledgeable society is the norm and no child misses school …" (African Union Commission, 2015:2). Further, The African Institute of Mathematical Sciences (AIMS) continues to enable African youth to shape the continent's future through STEM education. Individual countries have and continue to initiate different programs on STEM.

In Kenya's secondary education, there has been investment in STEM disciplines in their singularity with little or no attention to integration. The investment is aimed at preparing students for post- secondary education as well as STEM related careers. More generally it is for training personnel for industrialization and knowledge-based economy as envisioned in the Vision 2030 (Republic of Kenya, 2007). In the secondary curriculum, the science disciplines include biology, chemistry and physics, technology is offered under computer studies while engineering is offered in some schools through the subjects of building and construction, power mechanics, and drawing and design. Mathematics is a standalone subject. In learning, every student is expected to study at least two science subjects and mathematics. The current and outgoing curriculum document (Ministry of Education, 2002) does not link the disciplines, hence during implementation, integration happens with teachers and institutions that see and recognize the need to connect the disciplines. A similar situation is in the teacher training colleges, where the student-teachers take two teaching subjects and all are taught in isolation. An attempt has been made to integrate science subjects at primary level in the Competency Based Curriculum that is being rolled out (Republic of Kenya (RoK), 2017), this is however not projected in the secondary level.

Based on the past curricula, the initial perception of STEM education was that it was a means to improve instruction of the four individual disciplines. In 2006, the government initiated the integration of Information Communication Technology (ICT) into instruction (Ministry of Education, 2016) as a tool in the delivery of content, skills, and processes. Since ICT is an interactive media, its integration would facilitate students to develop the diversified skills needed and allow teachers and students to proceed at their differentiated learning paces. Teachers have ably practiced it (Mwei, Too, & Wando, 2011) and students' results have gradually improved (Kisirkoi, 2015). However, this was not achieved due to challenges such as lack of electricity connection, internet connectivity, training, digital content, limited digital equipment and digital infrastructure in some areas.

To take the STEM agenda further, a multi-sectorial approach was adopted. There have been a host of initiatives inside and outside the classroom to STEM education using single or inter-trans-multi-disciplinary approaches, with a focus to integration and pursuant of STEM careers. Two key national initiatives are the Kenya Science and Engineering Fair (KSEF) and the Young Scientist Kenya (YSK). In KSEF, students are expected to think critically, creatively, be innovative and apply knowledge, skills and attitudes learnt in class to develop projects. The YSK key agenda is to support young people to transform Kenya through science, technology and innovations. In both programs the young scientists' show-case their competitive projects as practical solutions to problems faced within their communities, national and global levels. The results have been improved and increased technological innovations from the initiatives. However, these initiatives do not engage all students. Those who do not participate in these projects do not get the opportunity to be trained and mentored to recognize and connect the different disciplines involved. There is a need to address this gap.

The Ministry of Education, through the Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA), introduced interventions to improve instruction of the STEM disciplines through in-servicing teachers (CEMASTEA, 2017). The teachers are trained on innovative pedagogies such as inquiry-based learning using the 5 E's (Engage, Explore, Explain, Elaborate and Evaluate) instructional model (Chitman-Booker & Kopp, 2013) which is necessary in the processes of critical thinking and problem solving. The training envisages that the STEM teacher should effectively deliver the curriculum and hence improve students' learning and performance. While the training programs build on teachers' knowledge, skills, values and attitudes towards the disciplines, there is little or no linkages between and among them. Furthermore, the Centre has been transforming selected schools into model centers and STEM hubs with the expectation that all students from the neighboring schools can use the facilities to work on STEM projects. With such plans, the government envisages to inspire the youth in pursuit of STEM-related pathways and careers. The main purpose of the initiatives is to narrow the gap between demand and supply of existing scientific and technical skills and to ensure school graduates have desirable skills for the work market. The challenges faced in the implementation of these initiatives are inadequate equipment and infrastructure in schools that are not model schools. The CEMASTEA programs have been ongoing and it is opined that the initiative will in future yield integration of the STEM disciplines as well as involvement of all teachers and stakeholders.

Engaging students in quality STEM education and integration requires programs to have a dynamic curriculum, instruction and assessment while promoting scientific inquiry. It is necessary for students and teachers to understand the vision of STEM education from both local and global levels. Further it is necessary that all teachers be provided with the proper professional development opportunities in preparation to facilitate and guide their students toward acquiring integrated STEM education. The emphasis should be on competency as a learning outcome towards the integrated disciplines. Prior to engaging with integration, there is a need to explore the attainment of learning outcomes of each discipline (English, 2016). It is prudent that strengths, weaknesses and opportunities concerned with each discipline are identified and addressed (Bybee, 2010). It is only then that the approaches to integration can be readily adopted and application of the knowledge so learnt in engagements within and without the class may be realized.

From the foregoing discussion, STEM integration in Kenya secondary schools has not been implemented within the classroom and where it happens outside the classroom, based on students' projects, not all students are involved. A question begging for a response is; how then will the Vision 2030 be realized when students, future employees, employers, and innovators are not prepared for the same? There is no official mode for STEM integration for all students.

Stem Integration: A Global Orientation

Single Discipline

STEM disciplines have their individual defining characteristics. Integration in a single discipline involves connecting content and concepts within the discipline. Curriculum content knowledge includes knowledge of the subject and its organized structure. Further, learning subject content matter is a pathway to learning and understanding concepts and according to Garden (1997), the development of conceptual understanding is evidenced in espousing a spiral curriculum. It is in such a curriculum that content knowledge is extended, refined and clarified periodically throughout schooling. Students' content acquisition needs to be orderly, sequential, from simple to difficult, integrative and hierarchical. Consequently, it reflects students' changing cognitive status as they progress up the grades. Fogarty (1991) proposed fragmented, connected and nested models. The fragmented model focuses on one major academic area at a time. Students move from one classroom to another and the subjects are taught by different teachers. Eventually, the model leaves students with a disjointed view of the subjects and hence the curriculum. This is the common practice in Kenya's secondary schools.

The connected model makes explicit networks within each discipline being taught and links one topic or skill to another. Polya (1957) argues that mathematical connections are processes used to support the comprehension of mathematical content. It is then necessary that deliberate efforts be made to account for the integration of these processes in mathematics instruction. More specifically, students should be able to; recognize and use connections among mathematical ideas, comprehend how the ideas inter-connect and build on one another to produce a rational whole, and recognize and apply mathematics in contexts outside of the discipline. These connections are necessary in examining a students' understanding of mathematical ideas (Garcia-Gacia & Dolore-Flores, 2018) and that of teachers (Eli, Lee, & Mohr-Schroender, 2013; Mhlolo, Venkat, & Schafer, 2012). Teachers should facilitate students in making connections between and among content and concepts in one discipline. For example, relate converting fractions to decimals when teaching fractions in mathematics.

The nested model emphasizes integrating several skills in each subject area. The norm in Kenya's context is delivery of knowledge with minimal connections, development and application of skills. The instruction of single disciplines forms the foundation for integration with other disciplines and hence the need to identify how integration can be done.

Science and Mathematics

Research has proposed five approaches to integration of science and mathematics; discipline specific, content, process, methodological and thematic (Davison, Metheny, & Miller, 1995; Miller, Davison, & Metheny, 1993). In their theoretical model, Lonning and DeFranco (1997) argued that integration of science and mathematics can be justified only when students' understanding of concepts in the two disciplines is enhanced. For example, the concept of data handling in mathematics, in which the skills such as data collection, organization and graphing are acquired, is necessary in allowing students to collect and represent scientific data.

Integration of the two disciplines has, however, been challenged in that mathematics and science have fundamental differences; their integration cannot be definite (Lederman & Neiss, 1997). The researchers argue that since the two disciplines have different natures, then there is need for review of each discipline before integration. This understanding is necessary since it is possible that not all aspects of the disciplines can be integrated and the model(s) of integration may differ.

Science, Technology and Mathematics (STM)

The initial aim of integrating technology with mathematics and science was to use technology as a tool to deliver the disciplines efficiently, effectively and accurately (Ministry of Education, 2016). Further integration has enabled development of digital content, contextualization of content and delivery through simulations and modeling. Integration of technology also enhances skills of communication and collaboration among learners and facilitators. It allows for increased time on practice outside the classroom and application of knowledge and skills learned to real-life situations and research. On the reverse, knowledge and skills acquired through science and mathematics can be applied to solve technological problems (Childress, 1996). The value of technology can be realized by analyzing how and to what extent the curriculum it delivers promotes students' engagement and performance in the disciplines as compared to none use.

Science, Technology, Engineering and Mathematics (STEM)

Integration of engineering into science, technology and mathematics disciplines is commonly related to engineering design. Engineering design is the process of devising a system, component, or process to meet desired needs (Accreditation Board for Engineering and Technolgy (ABET), 2010). It is a decision making process in which knowledge of disciplines using an interdisciplinary approach, is applied to produce optimal results. The process uses creativity and imagination often in an iterative manner. Such designs have been developed for example in medical engineering and financial engineering.

Research suggests that engineering design projects require skills related to problem solving, creative thinking, and communication (Thornburg, 2009). Peterson, (1990) suggests that engineering design is almost invariably a multidisciplinary approach. Ultimately, what is required is that students translate lessons learned in science and mathematics to solve problems in which learning goals are contextualized within engineering challenges (Berland, 2013). Berland argues that features in the lessons and learning activities for elementary learners use five steps of the engineering design cycle: ask, imagine, plan, create, and improve. Engineering design has been used as a pedagogical strategy to bridge science and mathematics concepts to solve open-ended problems, develop creative thinking, formulate solutions and make decisions, and consider alternative solutions to meet a variety of constraints while at the same time using technology as a tool. An example of STEM integration is in the pinhole to pixels' experiment (Berland, 2013). To successfully integrate diverse knowledge and skills, teaching tools such as schemes of work and lesson plans should be planned and designed with integration in mind.

From the literature reviewed, knowledge and skills in a single discipline is a pathway to integration of the STEM disciplines using interdisciplinary and multidisciplinary approaches. While this is the basis for STEM pedagogy, in Kenya it applies for the students who take up school projects in KSEF or YSK. Despite the global rise in interest in providing students with learning experiences that foster connection making across the STEM disciplines, there is no literature on STEM integration in Kenya.

Content And Concepts in Mathematics and Chemistry

The education system in Kenya uses a spiral curriculum in each subject area. The key concepts in mathematics include sets, numbers, variables, relations and functions, measurements, space and spatial relationships, proof, structure and probability (Garden, 1997) while those in chemistry include; chemical nomenclature, atomic structure, periodic table, Lewis structure, chemical reactions, stoichiometry and acid-base chemistry (Ball & Key, 2014). Despite the fact that mathematics concepts are applied in chemistry, these subjects are taught independently without planned integration of the concepts. However, it is notable that not all content can be integrated as each discipline has its expected outcomes. Further, integration works well in some specific areas whereas in others the specific discipline predominates.

Methodology

Data used in this study was drawn from two ongoing activities: an intervention dubbed "understanding mathematics with a purpose" and a document analysis of the conceptual connection between chemistry and mathematics. The intervention is aimed at assisting secondary school students to relate mathematics content and processes within and across grades, find everyday applications of the discipline and how each subject relates with other subjects and careers. Specifically, qualitative data was collected through observations and group discussions (Creswell, 2007) between November and December 2019 school holidays.

The target population was all secondary school students from three local centers in three counties totaling about 150. These were center A, B and C in Kisii, Kirinyaga and Nakuru counties respectively. With government restrictions on holiday tuition, a total of 50 students turned up.

The participants were girls and boys aged 14-19years, from diverse secondary schools, both public and private. They were systematically grouped in fives with at least one learner from Form 1, 2, 3 and 4. This arrangement was appropriate to allow for a longitudinal exposition of the topics to the benefit of all students. At center A, the students did not get time to connect the topics. Therefore, a set of data for analysis was randomly picked from each of the two other groups. Group 1 was from center B while Group 2 was from center C.

At the beginning, the students briefly highlighted the topics they knew, those that they had interest in and those that they had challenges with. The students informed the researchers that they revised on topics depending on what they thought was the relevant knowledge for each topic. The next task was to read through each topic, its brief content, specific objectives and suggested resources from the syllabus. They then discussed and indicated by way of arrows how the topics connected within and across grades. Reasons for the connection were explored and eventually presented to the whole group. While the connections were expected based on students' understanding of the content and process, the students were not inducted on it. This was to enable the enquirers to understand the students' knowledge of the connections.

Conceptual connections between chemistry and mathematics were done by the researchers. First was to identify the basic skills and knowledge a student must have necessary for integrating chemistry with mathematics. Then a conceptual connection was explored.

Table 1Conceptual Connection of Chemistry and Mathematics

	CONNECTION BETWEEN CONCEPTS	
	Chemistry concepts	**Mathematics concepts**
1.	Chemical Nomenclature	Numbers Simple statistics
2.	Atomic Structure	Numbers Ratios and proportions

3.	Periodic Table	Numbers Ratios and proportions Simple statistics
4.	Lewis Structure	Numbers Use of logarithms
5.	Chemical Reactions	Numbers Ratios and proportions
6.	Stoichiometry	Numbers Ratios and proportions Simple statistics
7.	Acid-Base Chemistry	Numbers Use of logarithms

Preliminary findings and analysis from the two activities are presented in the succeeding section.

Findings and Analysis

Content Connections Within One Discipline- Mathematics

The students connected the topics within a grade and across two or more grades while others were not connected at all. The connection chart developed by Group 2 is presented in Figure 1.

Figure 1 Group 2 Chart Showing Connections of Topics

The discussions by both groups generated massive data. Therefore, a sample of the data is used in analysis and with a particular focus on the topics that the students identified to be of interest or challenging to them.

Connections within grades

A sample of topics connected or not within a grade presented by both groups are tabulated in Table 2. The second column in the table shows a topic and its grade from the syllabus while columns 3 and 4 show the connected or not topic as identified by Groups 1 and 2 respectively.

Table 2 Groups' Connection of Topics Within Grades

S. NO	TOPIC/FORM	GROUP 1	GROUP 2
	Integers- 1	Algebra	None
	Factors- 1	None	GCD, LCM, Squares and Square roots
	Divisibility Tests- 1	None	Squares and Square roots
	Pythagoras Theorem - 2	Area of triangle	None
	Length- 1	None	Area
	Loci - 4	None	3-Dimensional Geometry
	Circles, Chords and Tangents- 3	Graphical methods	Graphical methods

Majority topics connected within grades were in Form 1 and one topic each in Form 2, 3 and 4. It was interesting that the groups had differences in the connections in all the topics tabulated other than the topic of Circles, Chords and Tangents that they had similar connection to Graphical Methods. This is related to the fact that in Graphical Methods there are equations of circles to be solved and tangents drawn to find gradient at a point and hence equation of curve.

Participants in Group 1 explained that Integers are used in Algebraic Expressions; they have both negative and positive values. Group 2 did not identify any topic connected to Integers. Group 1 did not link Factors to any topic, however, Group 2 found that Factors were related to GCD, LCM, and squares and square roots. They explained that these topics dealt with multiplication or division of natural numbers which was the key activity in Factors. Group 1 did not connect the topic of Divisibility Tests to any other while Group 2 informed that it was connected to squares and square roots because when testing natural numbers for divisibility, then one can identify a balance in the numbers such that it is possible to tell a number was a square of the other or a square root on the reverse. Group 1 found that Pythagoras Theorem in Form 2 was connected to Area of triangle because they used the theorem to find missing lengths in right angled triangles and hence the area. They also realized that in non-right triangles, if one was able to identify a base and find its corresponding vertical height using the theorem, then they could get the height. Group 2 found that the topic of Length was related to Area and that Loci were related to 3-Dimensional Geometry because some lengths and regions in 3-D geometry were similar to paths identified in Loci.

The similarities and differences of students' findings provide an opportunity to explore integration of the topics within a discipline and grade. This resonates with understanding a subject specific structure, terms and content.

Connections Across Grades

The participants connected more topics across grades than within grades. In this section, a sample of the topics they found interesting (Matrices and Statistics) and those they found challenging (Probability, Graphical Methods, Longitude and Latitude, and Locus) is used.

Table 3 Students' connections of mathematics topics across grades

S.NO	TOPIC	GROUP 1	GROUP 2
	Statistics I	Statistics II	Statistics II Graphical Methods
	Matrices	Matrices and Transformations	Linear Equations Matrices and Transformations
	Probability	None	None
	Graphical methods	Trigonometry II Area of Part of a Circle	Statistics II Area of Part of a Circle Lengths Cubes and Cube Roots
	Locus	Geometric Constructions	Pythagoras Theorem Circles, Chords and Tangents
	Longitudes and Latitudes	None	None

Both Groups connected Statistics I to Statistics II, noting that later was an advanced version of the former. Group 2 also noted that Graphical Methods dealt with collecting empirical data and graphing, hence the connection to Statistics II. Both groups connected the topic of Matrices (Form 3) to Matrices and Transformations (Form 4) on the understanding that the latter was a combination of two topics Matrices and Transformations (Form 2). Group 2 also connected the topic to Linear equations, arguing that similar equations are used in the matrices. These connections show the students identified with the corresponding topics and no wonder these were topics they had interest in.

Probability and Longitudes and Latitudes were not connected to any topic by both groups. Graphical Methods were connected to the Area of Part of a Circles by both groups. Group 1 also observed that it was connected to Trigonometry I while Group 2 observed that it was also related to both Statistics I and II for similar reasons mentioned above and further connected it to Cubes and Cube Roots because they drew cubic graphs. However, they were not clear how it connects with Length. Locus was connected to Geometric constructions by Group 1 because there are geometric constructions in the topic while Group 2 connected it to Pythagoras Theorem and Circles, Chords and Tangents, since there was need to find some dimensions of triangles formed hence the need for the theorem and that there were circle properties that were required in Locus.

The connections of the topics surprised the students. While they did most of the connections without much struggle, it was evident that they did not expect that some topics in Form 1 had connections within a grade and across all grades.

The analysis above, shows students' connections or lack of it and hence understanding of mathematical ideas (Garcia-Gacia & Dolore-Flores, 2018). Evidence on the performance on questions from these topics from the subject teachers and indeed Kenya National Examinations Council could come in handy. Where they did not connect the topics, it may imply that they are yet to be effectively exposed to the content.

Conceptual Connections Between Mathematics and Chemistry

Conceptual connections between mathematics and chemistry was based on sampled questions identified in a standardized national chemistry examination paper, 233/1 Chemistry Paper 1 Theory of Kenya National Examinations Council [KNEC] of various years. The questions were analyzed for mathematical content. The findings are as follows with samples of students' workings for those who did not score the question and expected mathematical solutions from the KNEC report. The report also made recommendations to teachers.

1. Calculate the heat of formation of carbon (II) oxide from the following data. (2 marks)

Expected Solution

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} \quad \Delta H_1 = -394 \text{ kJ/mol}$$

$$CO_{(g)} + \tfrac{1}{2} O_{2(g)} \rightarrow CO_{2(g)} \quad \Delta H_2 = -285.6 \text{ kJ/mol}^{-1}$$ (KNEC, 2011)

Samples of students' workings on the question:

1. $\Delta H = \Delta H_1 + \Delta H_2$

$-394 + -285.6 = -679.6$ KJ mol^-

2. $H = H_1 + H_2$

$394 + 285.6 = 679.6$ KJ mol^-

3. $\Delta H = \Delta H_1 - \Delta H_2$

$394 - 285.6 = 108.4$ KJ

Expected solution

$-DH_2 + DH_1$

$285.6 - 394 = -108.4$ KJ mol^-

This question tested concepts of enthalpy (heat) of formation. For the candidate to tackle this question, mathematical concepts on directed numbers and vector addition were necessary. It was found that most of the learners had challenges implying that there was inadequate grasp of the mathematical concept for use in the chemistry task or the students did not connect the mathematical operations with the requirement of the task. It is recommended collaborative teaching to inculcate the missing concepts and create their links between them (KNEC, 2011).

2. An unknown mass of anhydrous potassium carbonate was dissolved in water and the solution made up to 200cm^3. 25cm^3 of this solution neutralized 18.0cm^3 of 0.22M nitric (v) acid. Calculate the unknown mass of potassium carbonate (**K**=39, C=12, O=1) (3 marks) (KNEC, 2019)

A sample working of one student:

$$\text{Moles of } HNO_3 = \frac{18 x 0.22}{1000} = 0.00396 \text{ moles}$$

$$\text{Moles of } K_2CO_3 \text{ in } 25cm^3 \text{ solution} = 0.00396 \text{ moles}$$

$$\text{Moles of } K_2CO_3 \text{ in } 200cm^3 \text{ solution} = \frac{0.00396 x 200}{25} = 0.03168 \text{ moles}$$

$$\text{Molar Mass } K_2CO_3 = 138g/mol-$$

$$\text{Mass of } K_2CO_3 = 138 \text{ x } 0.03168 = 4.37184g$$

Expected Solution.

$$\text{Mols of } HNO_3 = \frac{18 x 0.22}{1000} = 0.00396 \text{ moles}$$

→ $K_2CO_3 + 2HNO_{3(aq)} \quad\quad 2KNO_{3(aq)} + H_20_{(l)} + CO_{2(g)}$

$$\text{Moles of } K_2CO_3 \text{ in } 25cm^3$$

$$\text{soln} = \frac{0.000396}{2} = 0.00198 \text{ moles} ✓½$$

$$\text{Moles of } K_2CO_3 \text{ in } 200cm^3 \text{ soln} = \frac{0.00198 x 200}{25} = 0.01584$$

$$K_2CO_3 = 138g$$

$$\text{Mass of } K_2CO_3 = 138 \text{ x } 0.01584 = 2.186 \text{ g}$$

This question was testing concepts of moles (Stoichiometry and chemical reactions). To be able to do this, candidates are required to be well grounded on numbers, ratios and proportions and basic statistics. The report noted that many candidates were not able to determine the mole ratio and hence unable to use it in the subsequent parts of the question. It is recommended that e teachers emphasize on calculations involving molar solutions and provide learners with the opportunities for further practice on questions involving the mole and related concepts.

3. The following are some half-cell electrode potentials with respect to copper

	E/V
$K^{+}_{(aq)} + e^{-} \longrightarrow K_{(s)}$	-2.99
$Na^{+}_{(aq)} + e^{-} \longrightarrow Na_{(s)}$	-2.75
$Ca^{2+}_{(aq)} + 2e^{-} \longrightarrow Ca_{(s)}$	-2.86
$Cu^{2+}_{(aq)} + 2e^{-} \longrightarrow Cu_{(s)}$	0.00
$Hg^{2+}_{(aq)} + 2e^{-} \longrightarrow Hg_{(l)}$	+0.87
$Ag^{+}_{(aq)} + e^{-} \longrightarrow Ag_{(s)}$	+0.79

Work out the e.m.f of a cell represented

$$Na_{(s)} \mid Na^{+}_{(aq)} // Ag^{+}_{(aq)} \mid Ag_{(s)}$$

(1 mark) (KNEC, 2009)

Samples of student workings:

1. e.m.f = E oxidized + E reduced

(0.79 - 2.75) = -1.96 v

2. e.m.f = E reduced - E oxidized

(-2.75- 0.79) = -3.54 v

3. E reduced + E oxidized = e.m.f

-0.79 + 2.75) = +1.96 v

Expected solution

$$E\ \text{oxidized} - E\ \text{reduced} = \text{e.m.f}$$

$$0.79 - (-2.75) = +3.54\ \text{v}$$

This question tested concepts of electrochemistry- calculation of the e.m.f. of a dry cell. For the candidate to tackle this question, understanding and application of directed numbers was necessary. The idea that the bigger the negative the more the reducing ability (electropositive) and the bigger the positive the more the oxidizing ability is mathematical. This implies that integration and application of mathematics concepts with those of chemistry were necessary to enhance achievement in the question (KNEC, 2009). However, dismal performance on the question by most candidates was evident.

From the analysis, it is clear that some mathematics concepts are embedded in chemistry concepts and are tested in chemistry examinations. It also implies that for a candidate to do well in chemistry, mastery of the mathematics content and concepts is necessary (Lonning & DeFranco, 1997). According to the KNEC reports, questions that required mathematics were dismally performed (KNEC, 2011). The analysis shows that candidates did not recognize and apply mathematical concepts in chemistry.

Discussion

The findings from this study show that students can connect content within mathematics discipline while they did not connect others. This shows the importance of teaching individual disciplines separately so that students master the content and concepts before integrating the disciplines (Fogarty, 1991; Lonning & DeFranco, 1997). The conceptual connection of chemistry and mathematics clearly shows that a substantial part of chemistry uses and tests mathematical content. However, candidates treat the subjects independently or have minimal understanding of the mathematics to apply in chemistry. The expected outcomes of STEM integration were not met (English, 2016) probably because they were not practiced in class. Further the reports of KNEC show the need for discipline integration. From the findings and literature reviewed, there is an identified need to integrate the STEM disciplines.

Proposed Model of Integration

First, there is a need to develop a philosophy on STEM integration. The following are consequently proposed:

1. Design an integrated curriculum involving industries that are consumers of the trained manpower. The design should be per subject and across subjects. The approach to implementing should be students centered based on expected outcomes. It should include instructional supportive materials. Further, since integration of ICT was implemented and is ongoing, each step of integration should use ICT as a tool. The steps are presented in narrative and figuratively (Figure 2) as follows;

    i. Integration within a single discipline. This is in line with the connected model of Fogarty (1991). This step helps students with the mastery of each discipline and identifying its content and concepts.

    ii. Integration of two disciplines. This should be done by identifying a theme across disciplines and hence an interdisciplinary approach. The students can then explore the connections between any two disciplines based on an identified theme. The themes could be conceptual, or problem based.

iii. Integration among all STEM subject's mathematics, biology, chemistry, physics, computer science and engineering; this step builds on step **(ii)** so that all disciplines are then involved.

iv. An integrated STEM approach will be achieved when students can identify and draw on knowledge, skills, values and attitudes from all disciplines in an integrated approach to solve current and future problems. This stage involves higher order and critical thinking skills. The approaches involved could be both interdisciplinary and multidisciplinary (ABET, 2010; Peterson, 1990).

The described model is presented figurative as follows.

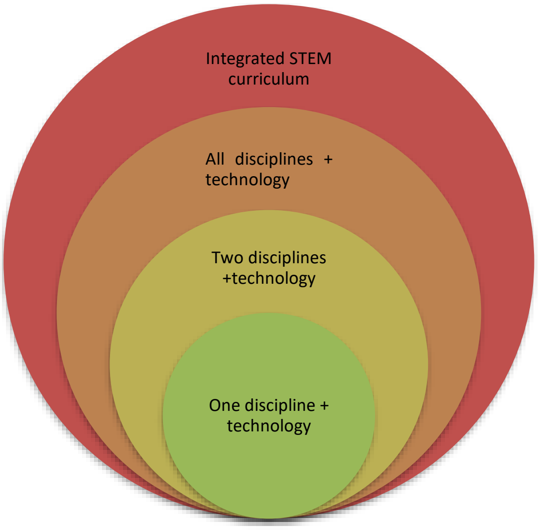

Figure 2: STEM integration model

2. There is need for clarity on approach to integration, that is in the implementation of the integrated curriculum which takes one or a combination of the approaches; single discipline, interdisciplinary, multidisciplinary and trans-disciplinary.

3. Revision of teacher education programs to be integrated; induct and train teachers both in-service and pre-service. The training on specific disciplines should be enhanced to training on the integrated curriculum at the level of CEMASTEA and pre-service teacher training institutions.

Conclusion

This study has reviewed the existing models of STEM integration in different contexts. The models show strengths, opportunities and challenges associated with STEM integration. Analysis of findings from the participants' show that students can connect or not content within mathematics which is an indicator of their understanding of the subject. However, conceptual connections between mathematics and chemistry

were not identified and used by students in chemistry national examinations resulting in nonperformance in questions requiring mathematics concepts. The findings are consistent with past findings. To improve learning, the need to integrate STEM subjects is identified and consequently, a stepwise model is proposed. The model uses technology as a tool for delivery. It is envisaged that the model shall enhance the performance of the STEM subjects and offer a solution for more informed integration between and among the disciplines and be applied in the secondary section of CBC. Further research on the integration of other science subjects and assessment of integrated curriculum is necessary to inform policy and practice.

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