IDENTIFYING THE ELEMENTS FOR THE DEVELOPMENT OF INTEGRATED STEM INSTRUCTIONAL MODULE FOR SCIENCE LEARNING AMONG SECONDARY SCHOOL STUDENTS IN NIGERIA

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Abstract

Integrated STEM education is one of the essential areas of research in recent times. However, there is no consensus among educational stakeholders on the definition and components of STEM instruction. Therefore, this article determined the Elements for the Development of Integrated STEM Instructional Module for Nigerian Senior Secondary School Science (genetics) Learning. Design and Development Research (DDR) design was adopted. Ten science education experts were purposefully selected and participated in the study. Experts' consensus was adopted to determine the components of the integrated STEM instructional modules (i-STEMim) for science (genetic) instruction. The learning objectives, elements and phases of the instructional modules were adopted from curriculum documents, and review of related literature. The final components were established using two rounds of experts' consensus. The findings from the first round of the survey showed items less than 75% consensus among experts were eliminated and the findings of the first round subjected to the second-round survey. The experts' consensus was used to identify the items that the experts agreed to be included in the instructional module. Four-point rating scale which yielded a reliability of 0.76 was used to collect quantitative data, while interview and documents provided the qualitative data.

The data collected were analyzed qualitatively and quantitatively using a simple percentage. The finding revealed seven objectives, seven elements, and five phases. The average score of all the items was high indicating that these learning components could be included in i-STEMim. The findings of this study could contribute to the current literature on the development of instructional modules for science instruction.

Keywords: Genetics, Instructional elements of STEM education, Integrated STEM education,

Introduction

The Science education curriculum has been undergoing reforms globally to meet the needs of a dynamic society. One of these reforms in science education is focus integrated-based education that will cater to the needs of learners in a dynamic society. Instructional benefits are associated with integrated-based curriculum because it provides less isolated science learning and provides more opportunities for meaningful learning experiences (Moore et al., 2014; Puspitasari, Herlina, & Suyatna, 2020). An example of integrated-based instruction or education is integrated STEM education. Similarly, instructional benefits of integrated STEM education have been reported which includes positive learning experiences, enhance achievement, assist students to be critical thinkers, innovators, and problem-solvers (Morrison, 2006; Sahin, Ayar, & Adiguzel, 2014). Students' experiences with integrated STEM education is similar to the way STEM professionals solve problems in real-life and relevant to their daily life. Given the importance of integrated STEM education, it is essential to consider how teachers can effectively guide students to learn using integrated STEM education. Therefore, an instructional module that will assist teachers to implement this approach is a vital factor. A critical review of related literature indicates that teachers do not have sufficient knowledge to implement STEM education (Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016). Internationally there is lack of instructional module to assist teachers to implement the approach (English & King, 2015; Nadelson et al., 2013; Osman & Saat, 2014), in Nigeria the case is not different. Other researchers attributed the lack of instructional module to the relative innovative nature of integrated STEM education (Roberts, 2012; Stohlmann, Moore, & Roehrig, 2012). The problem is further worsened because most teachers were trained to teach science subjects in isolation (Dare, Ellis, & Roehrig, 2018).

Available curricular materials do not seem to align with the goals of STEM education because the instructional modules failed to link science instructional contents to real-world problem-solving. It does not also provide the opportunity for multidisciplinary learning experiences and working in a team similar to the way experts work in real life. This has led to a lack of meaningful learning of science and has culminated in unsatisfactory performance in science especially at the secondary school level of education. Therefore, to maximise the benefits of integrated STEM education and achieve the goal of this reform as highlighted above, there is the need to prepare an integrated STEM instructional module to assist teachers to implement this approach.

The lack of integrated STEM education instructional module to guide teachers could affect teachers' self-efficacy (teachers' belief on their capabilities to influence positive students' learning) to implement STEM education in the classroom (Stohlmann et al., 2012). Quality instructional material is one of the most important factors that positively influence teachers' self-efficacy and effective classroom practices.

Although there is a consensus on the role of the teacher in a STEM-based instruction as a facilitator while learning is student-centred, however, there is disagreement among scholars about what qualifies STEM education instruction in the classroom (Honey, Pearson, & Schweingruber, 2014; Stohlmann et al., 2012). Garnering from literature, integrated STEM education could be in any of these forms, learning of a small content area of one STEM discipline in the context of one or more STEM discipline. Learning science in the context of engineering, technology, or both (Honey et al., 2014; Kertil & Gurel, 2016). Learning content from two or more STEM areas that is, learning the contents of engineering and mathematics (Kertil & Gurel, 2016). Integration among the four STEM areas and organising instruction around a theme or big idea where a relevant portion of STEM areas are integrated (Bybee, 2010). In this study, we focus on learning in a given area of science (genetics) in the context of engineering and genetic engineering as a prominent theme. The rationale for the use of engineering as a context for science instruction include it is the major component of STEM education and provides the basis for the integration of science and mathematics (National Research Council, 2012). Engineering drives complex and higher-order thinking through providing the opportunity for students to define the problem, generate ideas and make inferences. Engineering provides the platform for learners to think out of the box (Hiong & Kamisah, 2015).

The constructivist theory provides support for the preparation of i-STEMim. In this theory, the emphasis of learning is on the student and not on the teacher. Therefore, the instructional module is prepared for the student to interact with individually and as a group, in the process, their higher cognitive skills are engaged. The instructional module will provide the opportunity for students to construct their understanding and find a solution to the open-ended problem in line with the constructivist theory. Instruction based on the constructivist theory enhance learners' critical thinking, self-regulated learning and more in-depth understanding (Demiral, 2018). Educational document in the US highlighted that critical thinking and problem-solving skills are vital for effective learning of science (The NGSS Lead States, 2013). Therefore, students are expected to demonstrate the ability to plan and carry out an investigation, collect and interpret data, design solution, evaluate, and communicate the findings, these activities could foster their ability to think critically.

Genetic Teaching and Learning

Furthermore, a gleaned at literature indicated that genetics is a difficult concept to teach and learn (Atilla, 2012; Williams , Montgomery, & Manokore, 2012).

This could be attributed to the multidisciplinary nature of genetics which involves some aspects of mathematical probability with its application in genetic engineering. This probably suggests the best way to learn genetics will be through the use of interdisciplinary or multidisciplinary approaches. Therefore, the understanding of the abstract concept of genesis can be achieved through integrated STEM approach which will engage students actively in the learning process. Previous literature has reported that the active engagement of students in the learning process enhanced students understanding of the abstract genetic concept (Yaki, Saat, Sathasivam and Zulnaidi, 2019). Consequently, some of the elements to be embedded in i-STEMim such as open-ended problem, hands-on activities (simulation of how traits are inherited) and the authentic task could make abstract concept concrete for the students to understand.

Therefore, the main study investigated the effects of an integrated

STEM approach towards secondary school students' critical thinking skills and achievement in genetics. This article is part of that more extensive study and focuses on the determination of the components of integrated STEM instructional module (i-STEMim). Therefore, the objective of this article includes, determine the need for the preparation of i-STEMim for implementation among senior secondary school students. Determine the components of i-STEMim that could enhance critical thinking skills and achievement in genetics among senior secondary school students. To guide this study, the following research questions were formulated.

1. What is the need for the preparation of i-STEMim for implementation among senior secondary school students?
2. What are the elements of i-STEMim that could enhance critical thinking skills and achievement in genetics among senior secondary school students?

Methodology

To achieve the objectives of this study, Design and Development Research (DDR). Experts' consensus was adopted to determine the components to be included in i-STEMim. Two phases were employed: analysis, and design, and development.

Ten Science education experts were involved in validating i-STEMim. The experts were drawn from the university, secondary school and policymakers from the ministry of education. The experts are as presented in Table 1

Table 1: *Science Education Experts and Organization*

	Organisation	Number
1	National University of Malaysia (UKM)	2
2	Federal University of Technology Minna Nigeria	4
3	Federal Government College Minna	2
4	Ministry of Education	2

The experts were all PhD holders and among them were four professors. The experts validated i-STEMim, and some of the items were modified based on their suggestion.

Instrument and Procedures

The preparation of i-STEMim involves two phases adopted from the ADDIE. The first phase was the need analysis, and the second phase was design and development. In the need analysis phase, a four-point rating questionnaire was employed, an adopted 4-point Likert type scale; Strongly Needed (SN), Needed (N), Not Needed (NN), Strongly Not Needed (SNN) was adopted for rating each item. The questionnaire was validated by two science education experts and one expert in psychometric. The instrument was pilot tested and using Cronbach alpha the questionnaire yielded a reliability of 0.76. Review of related literature was carried out and content analysis to establish the need for developing the instructional module.

The design and development phase involves several steps. The first stage in this phase was the review of related literature and content analysis of curricular materials on the components of i-STEMim as highlighted in Table 2

Table 2: *Components of i-STEMim*

Components	Description
Learning Objectives	These are performance objectives that learners could acquire at the end of learning with the i-STEMim
Instructional Elements	These instructional elements adapted to be embedded in the instructional module to engage learners' higher cognitive skills
Instructional Phases	These are phases adopted from the engineering design process to provide the context to learn science and enhance critical thinking skills
Instructional Task	These are the design-based learning task included to help learners learn genetics and acquire critical thinking skills

The items of each component were subjected to two rounds of validation by the experts. The instrument for validating of the components was a four-point rating scale; Strongly Agree (4), Agree (3), Disagree (2) and Strongly Disagree (1). There was a section for experts' comments and observations. The items of each component were

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Determination of i-STEMim Components

The study adopted the phases of Dick and Carew; Analysis, Design, Development, Implementation, and Evaluation (ADDIE), these steps are linear, each of this element is dependent on one another (Dick, Carey, & Carey, 2001). The details of each phase are presented in the next section.

Need Analysis

This is the first stage in the ADDIE model to develop an instructional module, and the need analysis is done to understand the phenomenon and establish the need for the instructional module. The goal of i-STEMim was to enhance critical thinking skills and science achievement among senior secondary school students. To achieve this instructional purpose, a need analysis was performed to establish if there is an instructional need for i-STEMim. Several methods were employed to conduct the need analysis which could enhance the results (Borg & Gall, 1989). Firstly, review of related literature was conducted, followed by document analysis and interviews; seven secondary school science teachers were interviewed in Minna, to gain the understanding of instructional practices in the science classroom. The findings of this stage are explained in the results section

Design and Development

The curriculum content differs from one country to another; similarly, the science instructional content and syllabus with regards to genetics also differ. However, there is a consensus on the design components of a module. Hashim (1999) reported that good instructional module should include instructional design elements: learning goal and objectives, multimedia materials, instructional approach, instructional activities, and evaluation. The review of related literature and content analysis of curricular materials and textbooks were done to establish the items of each component. The components were subjected to two rounds of the survey as highlighted in figure 1

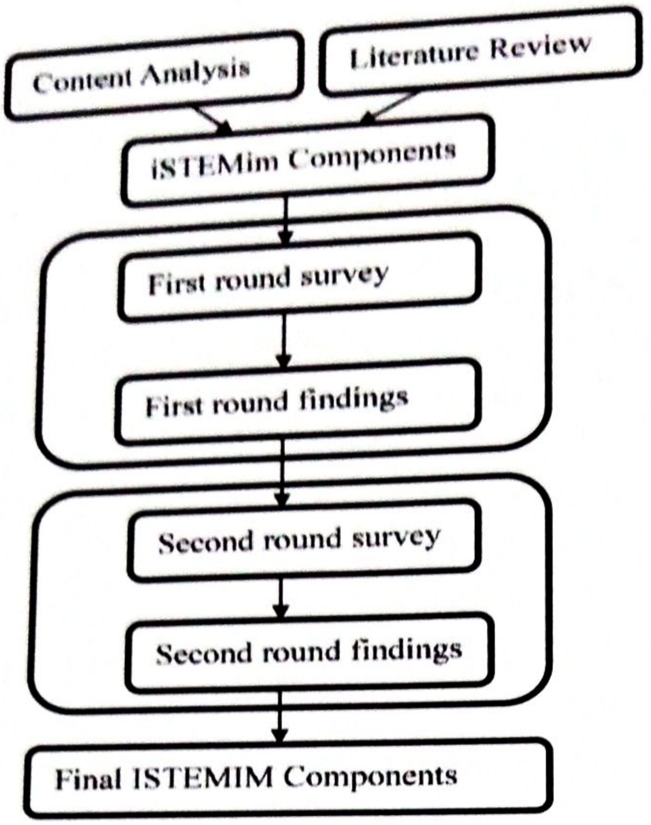

Figure 1. *Flow chart of Design and Development*

Data Analysis

Descriptive statistics were employed to analyze the quantitative data collected using four-point rating questionnaires for both the need analysis phase and the design and development phase. The analysis of the first-round survey was carried out, an item with the average percentage of 75% and above was retained because they are needed while items below 75% were discarded or omitted from round two (Kasim & Ahmad, 2018). The round two surveys were based on the findings of round 1 during the design and development phase.

Results

The purpose of this article is to identify and prepare the components to be embedded in i-STEMim. The findings of the study were presented based on the stated research questions. Research question 1; Is there any need for the preparation of i-STEMim for implementation among senior secondary school students? The findings are as presented below.

Findings from Need Analysis

Ten experts who were anonymous to each other were involved in need analysis which was considered acceptable. This was supported by Okoli and Pawlowski (2004) who reported that 10-18 experts are sufficient to achieve expert's consensus in design and development research. The findings of need analysis are as presented in Table 3

Table 3 *Experts' Consensus on Need Analysis*

	SA	A	NA	SNA	Remarks
There is a need for a paradigm shift from traditional to innovative-based instruction	9 (90%)	1 (10%)			Needed
Genetics is multidisciplinary and complicated, and it is suited for STEM-based learning	8 (80%)	2 (20%)			Needed
There is a need to improve critical thinking skills among secondary school students	10 (100%)	-			Needed
There is a need to improve students' STEM learning and skills	8 (80%)	2 (20%)			Needed
Teachers experience difficulties in implementing STEM integrated instruction	10 (100%)	-			Needed
Teachers need instructional modules to implement STEM-based instruction	10 (100%)	-			Needed
Average experts' consensus	91.67%	8.33%			Needed

Strongly Acceptable (SA), Acceptable (A), Not Acceptable (NA), Strongly Not Acceptable (SNA).

Table 3 indicates the findings of need analysis. The results show that an average of 91.67% experts strongly agree that there is need to develop the module while 8.33% accepted that there is no need to develop the instructional module for the target population.

Findings from document analysis seem to support the quantitative findings presented above. The policy document highlighted that "science and technology shall continue to be taught in an integrated manner in the schools to promote in students the appreciation of the practical application of basic ideas" (Federal Republic of Nigeria, 2004, P32). Consequently, this policy statement supports the development of i-STEMim because it is an integrated instructional module. However, the findings from the analysis of biology textbooks, syllabus, and scheme of work, showed that textbooks are subject-based and are written in isolation without links to other STEM subjects. Classroom observation indicated that traditional instructional practices dominate the Nigerian classroom. This implies that students are deficient in critical thinking skills which is an essential goal of science education because traditional instructional practices focus on lower-order thinking skills. Therefore, experts' consensus on the need to develop i-STEMim was achieved.

Findings from Design and Development

The design and development phase were done to answer research question two; what are the components of i-STEMim that could enhance critical thinking skills and achievement in genetics among senior secondary school students? Each component to be included in i-STEMim was subjected to two rounds of the survey. The results of the first round were harvested and sent out for the second and final round of survey for experts' consensus.

The first component was 15 performance objectives were proposed and placed in round one of the experts' consensus survey. The example of the learning objectives was that the students would be able to enhance their critical thinking skills (inference, recognising assumption, deduction, interpretation, and evaluation). Explain Mendel's first and second law, explain genetic terminology. Use proportions, percentages, and ratios to solve problems. Identify and practice an iterative process of designing a solution or a prototype through the engineering design process.

The second components are the elements that would be integrated into the instructional module that will engage the students' higher cognitive skills which could enhance critical thinking skills. Twelve (12) elements were proposed; open-ended problem, real-world scenario, questioning, hands-on activities, minds-on activities, inquiry, collaboration, authentic task, argumentation, group projects, teacher as *facilitator*, authentic assessment.

The findings after the first round showed that seven instructional elements received experts' consensus and these seven instructional elements were subjected to the second round of survey for experts' consensus. The findings of the second and final round of the experts' consensus produce the following instructional elements for inclusion in the instructional module; the open-ended problem, real-world scenario, questioning, hands-on activities, minds-on activities, inquiry, group projects and collaboration.

Third component; a good instructional module should also include the instructional context or strategy. In this instructional module, the engineering design process. The engineering design process is seen as a design-based problem-solving process because it promotes thinking out of the box and the phases scaffold students' learning (English & King, 2015; Hiong & Kamisah, 2015). After an extensive literature review, seven iterative engineering design process or cycle were proposed and placed in round one of the experts' consensus survey. The iterative engineering design process phases are the engaging problem, generation of ideas, brainstorm, designing prototype, testing prototype, and redesign and communicate findings. These phases went through round one experts' consensus survey. The findings after the first round showed that six phases received consensus from experts and these six phases were subjected to the second round of the survey. The findings of the second and final round of the experts' consensus produce five-phases for inclusion in the instructional module. The phases were the engaging problem, generate ideas design solution, evaluate and improve, communicate findings.

The instructional task was being provided in a design-based open-ended problem that requires learners to gain knowledge of the science and mathematics relevant to solve the problem and apply such knowledge to problem-solving. In this study, the i-STEMim assist learners to learn genetics and apply the genetic knowledge; Mendel's laws, principles of dominance, recessive, phenotype, genotype among others to design the solution and in the process enhance their ability to think. Therefore, the items of each component used based on experts' consensus are as presented in Table 4.

Table 4 *The summary of proposed the items of each component*

Component	Items
Learning Objectives	Enhance their critical thinking skills (inference, recognising assumption, deduction, interpretation, and evaluation)
	Enhance students' genetic learning and achievement (explain Mendel's laws, concepts, and terminology)
	Use proportions, percentages, and ratios to solve problems
	Explain the concept of Dominance and Recessive Trait
	Identify and practice an iterative process of designing a solution through the engineering design process.
	Identify the relevance of STEM to their daily lives.
	Define the problem and generate ideas
	Enhance students' motivation and learning satisfaction
Instructional Elements	Open-ended problem
	Real-world problem
	Questioning
	Hands-on activities
	Minds-on activities
	Inquiry
	Group project
	Collaboration
Instructional Phases	Engaging the problem
	Generate ideas
	Design solution
	Evaluate and Improved
	Communicate findings
Learning Task	Engineering a unique savannah hare that will benefit the community

	Creating an insect for aesthetic value in a community that insects are valued
	Settling a dispute of the appearance of a new trait in a family

Table 4 shows the summary of all the elements that achieved experts' consensus to be embedded in the integrated STEM teaching and learning module.

Discussion of Results

The need to provide instructional modules to guide the implementation of innovative instructional materials that will enhance meaningful learning is at the forefront of educational research. Therefore, this study determined the elements for the development of integrated STEM instructional module for Nigerian senior secondary school science learning.

The finding of the study indicated that there is a need to develop integrated STEM instructional module. The findings agree with the earlier findings of Kasim and Ahmad (2018) who reported that experts' consensus should be 75% and above. This finding could be attributed to the fact that traditional instructional approach is prevalent in the classroom and teachers may not have the expertise to implement an innovative instructional approach. Hence, the respondents in this population believe that there is a need for i-STEMim. Therefore, experts' consensus on the need to develop i-STEMim was achieved.

The finding also indicated that experts agree that instructional elements such as open-ended problem, questioning, hands-on, minds-on and inquiry, among others should be included in the module. This finding concurs Puspitasari et al. (2020) with who reported that physics teachers in Indonesia agreed that there is the need for an integrated STEM e-module to foster students' critical thinking skills. This finding can be attributed to the fact that the respondents in this population believe that these elements will foster students' critical thinking skills and deepened students' understanding of the genetic concept. This implies that the experts believed that these elements could link what students learn in the classroom to their daily lives and make learning more meaningful.

Conclusion

Given the findings of this article, it can be concluded that this article established the instructional components to be embedded in i-STEMim based on experts' consensus. Therefore, the result could provide a guide for science and mathematics textbooks, authors, to write textbooks incorporating these elements to emphasize integrated STEM-based learning. The findings could also provide useful guides for curriculum developers. Policymakers could benefit immensely from the results especially now that the trends of educational reform are in STEM education. It is hoped that these elements, when incorporated in the instructional module, will promote students' higher cognitive engagement in the learning process and promote effective and meaningful learning and thinking skills.

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