Development and Evaluation of Innovative Instructional Module for Teaching and Learning of Biology in Senior Secondary Schools

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Abstract

Science, Technology, Engineering and Mathematics (STEM) education is an innovative instructional approach in the 21st century. Given its innovative nature, there seems to be a paucity of the instructional framework to guide teachers to implement it in the classroom. Therefore, this study focused on the development and evaluation of innovative instructional module for biology instruction among secondary school students. In the first phase, the instructional module was developed based on Analysis, Design, Development, Implementation and Evaluation (ADDIE) model and the framework for integrated STEM instruction. Ten (10) experts in science education validated the innovative module called integrated STEM instructional module (i-STEMim) in a two- round validation process. In the second phase, quasi-experimental design was adopted to determine the effects of the prepared i-STEMim. Using simple randomly sampling, two secondary schools were assigned to the i- STEMim and conventional group. To determine the effect of developed instructional material, quasi-experimental design was used. The i-STEMim group was 30 students while the traditional were 32 students. Pre-test and post-test data were collected using biology achievement test. The data were analyzed using mean and standard deviation, dependent t-test and Multivariate Analysis of Variance (MANOVA). The finding shows that i-STEMim has good content validity and was suitable. dependent t-test analysis shows that the innovative instructional module enhances students' genetic achievement more than the conventional group. There was a significant difference between students that learned with i-STEMim and the conventional method in favour of the i-STEMim group. The findings of this study have implication for teachers' instruction practices.

Keywords: Integrated STEM instructional module, Genetics, and Engineering design process

Introduction

The current reform on Science Education is focusing on integrated STEM education because it holds the promise to equip students with competences, knowledge, and indispensable skills for lifelong living. The essential skills are the ability to integrate knowledge and competences from STEM disciplines to solve real-life problems and develop innovative products (Khalil & Osman, 2017). Nonetheless, observing the instructional practices in the present classroom seem to fall short of this.

The current classroom instructional practices of teaching STEM discipline or subjects in silos and not integrated is less relevant to dealing with real-life problems which are multidisciplinary in the real world. It is reported that complex learning task in science could be taught successfully using integrated STEM-based instruction which provides the students with real-world experience that will cumulate in meaningful and lifelong learning (Moore et al., 2014). This is because of the integrated STEM-based approach to learning places premium on solving a real-world problem, life-long learning and more in-depth understanding or meaningful learning (Czerniak & Johnson, 2014; English & King, 2015). It provides the opportunity for students to engage in defining an open-ended problem, and generation of ideas and integration STEM competencies and knowledge to deal with the open-ended problem (Chew, Idris, Leong, & Daud, 2013) and it assist learners to acquire 21st-century skills (Bybee, 2010; Khalil & Osman, 2017; Wan Husin, Mohamad Arsad, Othman, Halim, Sattar, Osman, & Iksan, 2016).

Given the importance of STEM education, there is a lack of expertise by teachers to teach using STEM instructional approaches (Cunningham & Carlsen, 2014; Dare, Ellis, & Roehrig, 2018). This could be ascribed to the lack of instructional materials to guide teachers (Stohlmann, Moore, & Roehrig, 2012). For example, Gimba, Hassan, Yaki, and Chado (2018) reported a lack of quality and suitable instructional materials for effective learning in Nigerian secondary schools which results in children unsatisfactory achievement in science. They recommended the provision of innovative science and technology instructional materials that will relate science to the real-life situation to enhance meaningful learning. An example of such innovative instructional strategies is integrated STEM education

Previous literature has reported the effect of integrated STEM-based instructional material or module on students‟ achievement in science (Lee & Kamisah, 2015; Nuswowati & Purwanti, 2018; Yasin, Amin, & Hin, 2018). For instance, Yasin, Amin and Hin (2018) prepare a module for biotechnology instruction in grade 11 (eleven). Achievement test and questionnaires on 21st-century skills were used for data collection. The findings of the study showed that the module enhanced students‟ achievement in biotechnology and twenty-first-century skills. Similarly, Lee and Kamisah (2015) developed an inquiry module. The instructional was developed to help secondary school students learn biology. The module was characterized by inquiry and problem-based learning. The inquiry activities were designed based on engaging, explore, explain, elaborate and evaluate (5E). Nuswowati and Purwanti (2018) Investigated the effects of critical thinking style module in the learning of chemistry. The findings indicated that there were positive learning outcomes in hydrolysis and buffer materials. There is a lack of integrated STEM-based modules on the concept of genetics (genetic terminology, laws and probability). Genetics was chosen as the instructional content because related literature indicated that students have learning difficulties in genetics globally (Atilla, 2012; Yaki, Saat, Sathasivam, & Zulnaidi, 2019). In view of this, students‟ performance in genetics continues to be an issue of concern. Hence, the need for this iSTEMa instructional material (i-STEMim) to redress the learning difficulties. STEM education is an instructional approach which provides the opportunity to utilize scientific procedures and design techniques in solving open-ended problem involving the use of higher cognitive abilities. It involves the use of the engineering design process as a platform to learn scientific concepts. Students are presented with a multidisciplinary problem scenario to solve and in the process engage in meaningful learning

Research Questions

To achieve the objectives of this study, the following research questions were formulated.

1. Do experts adjudge i-STEMim appropriate for learning genetics by secondary school students?

2. Is there any difference between secondary school students who learn using i-STEMim and those who learn with the conventional method in genetic achievement?

Hypothesis

1. There is no significant difference in genetic achievement between secondary school students who learn using i-STEMim and those who learn with the conventional method.

Research Methodology

Quasi-experimental design. The descriptive method was used to determine the validity, of the i-STEMim as well as expert views on the appropriateness of the instructional module for learning genetics among secondary school students.

Ten (10) science education specialists were used to evaluate the develop module during the development phase. Okoli and Pawlowski (2004) highlighted that 10 to 18 experts are suitable for validating a module to established experts" consensus.

Population, Sample and Sampling Techniques

To determine the effects of i-STEMim, a sample comprised of sixty-two (62) senior secondary school students were used. Two schools were selected from Minna, Niger State, Nigeria and randomly allocated to the i- STEMim and traditional group. The i-STEMim and traditional group were made up of thirty (30) and thirty-two

(32) students respectively. This sample size is supported by the central limit theory which highlighted that a sample size of thirty (30) and above participants is likely going to be normal in distribution and adequate for experimental research.

Preparation of the i-STEMim

Previous literature shows that integrated STEM education has been implemented using several approaches; problem-based learning, inquiry-based learning, and project-based learning (Crotty, Guzey, Roehrig, Glancy, Ring-Whalen, & Moore, 2017; Lee & Kamisah, 2015; Toma & Greca, 2018). Other researchers highlighted some important factors to consider when developing STEM education module; engaging instructional setting and adopt engineering design process (Walker, Moore, Guzey, & Sorge, 2018). Therefore, a 5 stage Engineering Design Process (EDP) was adopted as an instructional to integrate science and mathematics (Capobianco, Yu, & French, 2015; Shahali, Halim, Rasul, Osman, & Zulkifeli, 2016). The iterative stages are engaging the problem, gather ideas, plan solution, evaluate and improve, and communicate findings.

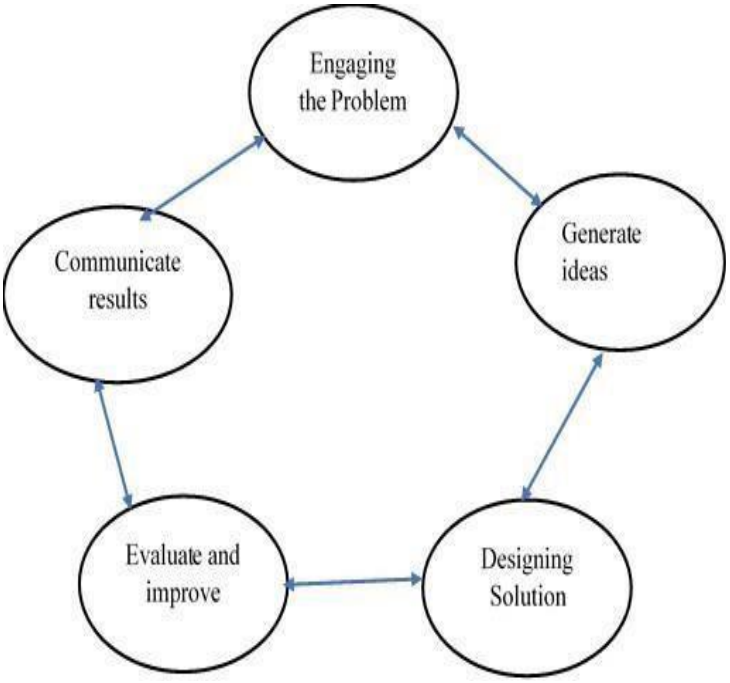

Figure 1: Engineering Design Process

Figure 1 indicates students engage the problem, students are expected to analyse the problem scenario into important components. In the second phase, students generate ideas needed to solve the problem which will include science and mathematics concepts and principles, highlight the materials needed to solve the problem. Students design and develop a solution, The solution could be a prototype or artefact. The students appraise their results, improve their solution and communicate the outcome.

In the second phase which is also the Design and Development Research (DDR), the framework of Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model was adopted (Dick, Carey, & Carey,
2001; Fadzil & Saat, 2019). The ADDIE model provides the latitude to integrate instructional activities, approaches, assessment instruments and procedures. Four phases were adopted for this study which includes: analysis, design, development, and implementation and evaluation. A brief explanation of the ADDIE model adopted is presented in the next section.

Analysis
This involves the gathering of relevant information to identifying the needs to develop the instructional materials. This was achieved, through policy content and textbooks analysis. Twelve (12) science education experts were also interviewed to provide the necessary information on the need for preparing the i-STEMim using unstructured interviews. Results from teachers that were interviewed revealed that most teachers lacked the required proficiency to implement STEM education approaches and there are teaching resources to guide the teachers. Science teachers‟ response also indicated that genetics is a difficult concept to teach. Findings from document analysis indicated the following: 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" (FRN, 2004).*

Consequently, this policy statement supports the development of i-STEMim, because it is an integrated instructional material. However, the findings from document analysis of biology textbooks, syllabus and scheme of work, exposed that *textbooks were written in silos without links to other STEM subjects. Therefore, the textbooks are not in line with the policy document.* This finding agrees with Olayinka (2016) who reported that instructional materials are not available in Nigerian schools making teachers resort to traditional instructional practices. Given the preceding, the need to develop the i-STEMim was established

Design of i-STEMim

This involves the selection of the instructional elements and phases of the i-STEMim iterative cycle, activities, guides and determining the learning content and objectives, example, materials such as pictures, charts and textbooks as well as hands-on materials that will support the learning process. These materials are carefully selected to assist students to achieve the objectives of the instructional material.

Development

The instructional materials were translated into a whole package or outline with components of the learning process. The instructional material went through two stages of validation. The first stage involves ten experts who validated the module and based on experts" agreement the module elements, activities, objectives, practicability and legibility were modified. The instructional material was sent for the second evaluation where there was experts" consensus on the components of the i-STEMim for learning genetics.

Ten experts which included science education lecturers in the university and secondary school teachers were involved in validating the instructional material. The result of experts" validation which took place during the development is presented in the results section

An example of a task using i-STEMim

Instructions: In this approach, students are expected to play the role of a bioengineer. Apply the principles and laws of genetics, mathematics thinking (probability and percentage) to solve a problem. The solution should benefit the present society and future generations. The teacher acts as a facilitator. One of the i-STEMim open- ended problem and task that requires students to use the engineering process to solve the open-ended problem and, in the process, engage in meaningful learning of genetics.

> ***Open-ended Problem:*** *A client from a rural area in northern Nigeria where moth insects add to the aesthetic nature of the environment, but these insects are threatened with extinction. Your group is contracted to engineer a unique moth insect for an exhibition. The model produce should be good, and useful to society to convince the client to invest.*

Implementation and Evaluation

This two phases in this phase take place simultaneously during classroom instruction, hence they are considered as one phase. The pre-test and post-test control group quasi-experimental method were used to examine the effect of i-STEMim on students" academic achievement in genetics during implementation. The experimental group learned using the i-STEMim (i-STEMim group) while the control group learn using the traditional group. The implementation lasted six weeks. The genetic achievement test was made up of forty objective questions which were used for data collection. The items in the genetic instrument were made of Mendelian Laws, genetic terminology and genetic probability subsections. The reliability of the subsections of the instrument was between 0.71, 0.74, and 0.76 which was considered adequate (Sekaran & Bougie, 2010). A pre-test was administered, followed by the intervention and after the intervention as post-test. The data collected was analysed using dependent t-test and Multivariate Analysis of Variance. Similarly, data generated from questionnaires were used to determine the validity and suitability of i-STEMim.

Results

The results of this study were presented based on the stated research questions. Research question 1; Do experts adjudge i-STEMim appropriate for learning genetics by secondary school students? To answer this research question Gregory content validity criteria were adopted.

The findings on the content validity were based on Kasim and Ahmad (2018) who reported that the content validity of instructional material or module should fulfil the following criteria: relevant to the instructional needs of the target population, the method of implementation was satisfactory. Time allocated to implement the module was adequate, improve students' achievement and enhance positive attitudes towards learning (Kasim & Ahmad, 2018). Gregory content validity criterion was also adopted to determine the validity of the instructional module as presented in Table 1

Table1: *Gregory Content Validity Criteria*

S/NO	Range Value	Validity Criteria
1	80 – 100	Very High
2	60 – 79	High
3	40 – 59	Medium
4	20 – 39	Low
5	0 – 19	Very Low

(Retnawati, 2015)

Similarly, Linn (1989) reported that the percentage of experts‟ agreement for each criterion of an instructional module should be 70% and above as good validity while below 70% is not good validity. Therefore, the validity of iSTEMim is presented in Table2.

Table 2: *Expert consensus on the validation of i-STEMim*

Component	Item	Good	Not Good	Remarks
i-STEMim Presentation	The arrangement of the instructional material was suitable	90	10	Good
	The clarity of the images was good and attractive	80	20	Good
	The module was attractive and legible	70	30	Good
	The instructional material is user-friendly	100	0	Good
STEM Approach	There are adequate driving questions to drive learning	70	30	Good
	The i-STEMim phases are logically arranged	80	30	Good
	The instructional material will encourage learners‟ active engagement	100	0	Good
	Engineering design process offered the framework for science, technology and mathematics integration.	100	0	Good

	The open-ended and real-world problems characterized the module.	80	20	Good
The goal of the module	The i-STEMim could improve genetic instruction and achievement	90	10	Good
	Promote learners‟ active engagement and participation	100	0	Good
Activities	Design-based tasks were provided	80	20	Good
Target Population	The i-STEMim is appropriate for the targeted level of students	90	10	Good
Time Allocation	Adequate time for the activities was allocated	70	30	Good

Table 2 shows that all the criteria in the instructional material have 70% and above experts‟ consensus, and the average experts‟ consensus is approximately 80%. This shows consensus among the ten experts, the i-STEMim has good content validity and suitable for the target population (Linn, 1989; Polit et al., 2007; & Retnawati, 2015).

Research question 2 was translated into hypothesis one; There is no significant difference in genetic achievement between secondary school students who learn using i-STEMim and those who learn with the conventional method.
To test this formulated hypothesis both dependent and independent t-test was employed to perform the within- group comparison and between-group comparison respectively and the result is presented in the next section **The effects of i-STEMim**

The within-group comparison was done to determine the effect of treatment and the effect size of the treatment between pre-test and post-test. A dependent t-test was used, and the result presented in Table 3

Table 3: *Within-Group Comparison of i-Stemim and Conventional Group*

Dimension	**Group**	**Pre-test Mean**	**SD**	**Post-test Mean**	**SD**	***t-value***	***df***	***p-value***	***d2***
Genetic Laws	i-STEMim	10.53	2.20	14.27	4.47	-3.95	29	.00	1.06
	Conventional	11.16	2.52	11.63	3.27	-.72	31	.47	0.16
Terminology	i-STEMim	9.93	2.95	12.23	3.70	-3.22	29	.01	0.68
	Conventional	10.41	2.61	10.69	3.30	-.40	31	.69	0.09
Probability	i-STEMim	10.47	2.40	13.33	2.85	-4.10	29	.00	1.08
	Conventional	10.91	1.84	11.03	3.25	-.17	31	.86	0.04
Overall Score	i-STEMim	30.93	6.06	39.83	3.10	-5.39	29	.00	1.84
	Conventional	32.48	5.94	33.35	3.10	-.74	31	.46	0.18

Table 3 shows the within-group comparison of subsection and the overall genetic score of the two groups. The result indicates there a significant mean difference in the within-group comparison of students who learn with i-STEMim. The effect size of students" achievement in genetic laws, terminology and probability are large, medium and large respectively. In contrast, there was no significant difference in the within-group comparison of the conventional groups in all subsections of genetic achievement. The effect size of conventional groups achievement in genetic laws, terminology and probability are all small effect size (Cohen, 1988).

The mean and standard deviation of the overall genetic score of i-STEMim group shows pre-test (M=30.93, SD= 6.06) and post-test (M=39.83, SD=3.10) respectively. The dependent t-test shows a significant difference between the pre-test and post-test $t(29)=-5.39$, $p(.00) <.05$. d^2 was 1.84, showing the effect size was large. This implies that i-STEMim has a large impact on fostering meaningful students" genetic learning and achievement. The conventional group show the pre-test and post-test are (M= 32.48, SD=5.94) and (M=33.35, SD=3.10) respectively. The mean difference was not significant. $t(31)= -.74$, $p(.46)>.05$. The magnitude of the effect size was ($d^2=0.18$), indicating a small effect size.

Research question two; Is there any difference between secondary school students who learn using i-STEMim and those who learn with the conventional method in genetic achievement? To answer this research question, the mean and standard deviation was employed.

Table4: *Post-test Mean and Standard Deviation of the i-STEMim and Conventional Group*

Dimension	**Group**	**Post-test**		**Mean difference**
		Mean	**SD**	
Genetic Laws	i-STEMim	14.27	4.47	2.64
	Conventional	11.63	3.27	
Terminology	i-STEMim	12.23	3.70	1.54
	Conventional	10.69	3.30	
Probability	i-STEMim	13.33	2.85	2.30
	Conventional	11.03	3.25	
Overall Score	i-STEMim	39.83	3.10	6.48
	Conventional	33.35	3.10	

Table 4 shows the mean and standard deviation comparison of the i-STEMim and conventional group. The post means of the i-STEMim group in all the subscales of the genetic score was higher than the conventional group. The overall results show that the i-STEMim group mean was higher 39.83 than the post-test mean 33.35. The mean difference of 6.48 in favour of the i-STEMim group.

Given the preceding, to determine the means difference between i-STEMim and conventional group in the post-test score of students in genetic achievement subsections Multivariate Analysis of Variance (MANOVA) was adopted because MANOVA can be used to compare more than two dependent variables. The findings are as presented in Table5

Table5: *MANOVA Results for Genetic Achievement Test*

Effect		Value	F	df	Error df	*P-value*
Intercept	Pillai's Trace	.34	24.43	3	60	.00
	Wilks' Lambda	.42	24.43	3	60	.00
	Hotelling's Trace	1.10	24.43	3	60	.00
	Roy's Largest Root	1.10	24.43	3	60	.00
Group	Pillai's Trace	.06	1.65	3	60	.01
	Wilks' Lambda	.71	1.65	3	60	.01
	Hotelling's Trace	.08	1.65	3	60	.01
	Roy's Largest Root	.08	1.65	3	60	.01

Table5 shows that there is a significant difference between the i-STEMim group and the conventional group in the dependent variable (genetic achievement). Wilks' Lambda = 0.71 F (3, 95) = 1.653, p = (0.01) < 0.05, indicating there is a significant difference between the two groups in all sub-section of genetic achievement. Therefore, the between-group analysis was presented for each genetic sub-section and the overall genetic score. The result is presented in Table6

Table 6: *Between Subjects Comparison of Genetic Achievement*

Source	Dependent Variable	Df	Mean Square	F	*P*-value	Partial Eta Squared
Group	Genetic laws	1	17.04	2.46	.01	.043
	Terminology	1	79.68	4.38	.04	.025
	Probability	1	9.07	.90	.02	.050
	Overall Score	1	61.01	1.42	.02	.061
Error	Genetic laws	60	6.92			
	Terminology	60	18.19			
	Probability	60	10.04			
	Overall Score	60	42.81			

Table 6 shows the comparison of the genetic subsections of the two groups. The result indicates there a significant mean difference between the i-STEMim and conventional groups in all subsections of genetic achievement. The overall genetic achievement score $F(1, 97) = 1.42$, p = (0.02) < 0.05, with the mean of the i-STEMim group (39.83) was significantly higher than the mean of the traditional group (33.35*)* The partial η^2 = 0.061, indicating that approximately 61% of the total variance genetic terminology is accounted for by the instructional approaches. Therefore, the hypothesis which stat that there is no significant difference in genetic achievement between secondary school students who learn using i-STEMim and those who learn with conventional method is rejected.

Discussion of the Result

This study aim was the development and evaluation of innovative instructional module for biology teaching and learning among secondary school students. The ADDIE instructional model and integrated instructional framework provide support for the preparation of i-STEMim.

The findings show that the validity of i-STEMim was accepted and have good content validity. This concurs with Retnawati (2015) who reported that the total content validity index of .70 and above of a developed instrument is considered to have good content validity. The findings on validity also concur with Siew and Ambo (2018) who reported that developing instructional material based on the constructivist theory, and ADDIE model provides researchers with the potential to design and developed effective STEM-based instructional module. This study provided the impression that developing STEM module based on the fundamental components of STEM instruction such as engineering design challenge, opportunity to integrate science and mathematics, real-world problem, student-centred approaches, and use engineering design process throughout the unit. These seem to provide the opportunity for the instructional material to be valid.

The within-group result to answer question one indicates that learning using i-STEMim enhance students" genetic achievement compare to a similar group who learn with the conventional method. The result agrees with Lee & Kamisah (2015) who found that STEM-based module enhances students achievement in biology. Similarly, the between-group comparison to answer question two indicated that the i-STEMim group had higher achievement scores compare to their colleagues in the conventional group. The findings also show that there is a significant difference between the i-STEMim group and the conventional group in favour of the i- STEMim group. This result collaborated with the findings of numerous researchers who reported that teaching and learning using integrated STEM modules foster students" achievement in science (Nuswowati & Purwanti, 2018; Yasin et al., 2018). For instance, Yasin et al. (2018) prepare a module for biotechnology instruction in grade 11 (eleven). Achievement test and questionnaires on 21st-century skills were used for data collection. The findings of the study showed that the module enhanced students" achievement in biotechnology and twenty-first-century skills.

The results also agree with Belluigi and Cundill (2015) who reported that in science education, the use of instructional strategies that are learner-centred characterised by the exchange of ideas, problem-solving and inquiry activities enhance students' learning outcome. This could be attributed to the explicit integration of the engineering design process in solving an open-ended problem. It also provided an opportunity for the students' active engagement. The learning environment was characterised by collaboration and exploration which could have foster students learning and achievement.

Conclusion

This interdisciplinary instructional material was prepared and implemented based on the premix that isolated STEM subject instruction is not suitable or appropriate to live in the 21st-century and beyond. The premium in the 21st-century is lifelong learning and the ability to integrate knowledge from different sources to solve a problem. Given the findings, it was concluded that the i-STEMim has good validity based on experts" consensus. The i-STEMim was found to an effective instructional module for science learning. Thus, this study may provide a guide for teachers to develop an integrated STEM instructional module for classroom instruction. The i-STEMim was developed to focus on genetic instruction at the senior secondary school level, it could be adopted for teaching and learning of other science concepts.

Recommendations

Given the findings of this study, it is recommended that:

1. Teachers should be encouraged to develop an innovative instructional module for teaching and learning science in an integrated manner.
2. Teachers should be encouraged to implement integrated STEM-based Module in their science and mathematics instruction.

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