

**PREPARATION AND VALIDATION OF AN INTEGRATED STEM INSTRUCTIONAL MATERIAL FOR GENETIC INSTRUCTION AMONG YEAR 11 SCIENCE STUDENTS**

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**ABSTRACT**

Integrated STEM education holds the promise for students' meaningful science instruction. However, the implementation of integrated STEM-based approaches for science learning might be difficult for teachers due to the lack of expertise and instructional materials. Therefore, this study focused on the preparation and validation of an integrated STEM instructional material (iSTEMim) for genetic instruction among Year 11 science students. The study employed a mixed method design. Five stages of ADDIE which consisted of Analysis, Design, Develop, Implement and Evaluate were adopted to prepare the iSTEMim. Ten (10) science education experts participated in the validation of iSTEMim, and thirty students participated in determining its reliability. A quasi-experimental design was adopted to determine the effects of the prepared iSTEMim. Two secondary schools were randomly assigned to the iSTEMim and traditional group. The two groups were made up of 30 and 32 students respectively. Data were collected using questionnaires and genetic achievement test. The data were analysed using descriptive and t-test statistics. The findings show that iSTEMim has good content validity and its reliability was acceptable. Moreover, the results revealed higher achievement scores for students using the iSTEMim when compared to the traditional method. Consequently, the findings of the study could contribute to the current literature on STEM education research. The iSTEMim could serve as a guide for science educators to implement STEM-based instruction in the classroom.

**Keywords:** *Engineering Design Process, Genetics and Integrated STEM Instructional Material*

**INTRODUCTION**

One of the recent reforms in science education is focused on integrated STEM education as it holds the promise to prepare students with the knowledge, and essential skills for meaningful living in the 21st-century and beyond (Stohlmann, Moore, & Roehrig, 2012). The core idea of STEM education is to integrate knowledge from two or more STEM discipline to solve problems, to inculcate lifelong learning and to enhance critical thinking skills (Khalil & Osman, 2017). Nevertheless, the present educational practices in many classrooms seem to fall short of this as classroom instructional practices of STEM subjects are in isolation (Dare, Ellis, & Roehrig, 2018; Masters, 2016). Teaching STEM subjects in isolation may not grant students with the knowledge needed to solve ill-structured problems which are usually multi-disciplinary. Given the enormous potential of integrated STEM-based instruction, however, teachers seem to lack the know-how to implement STEM-based instruction. This could be

attributed to the lack of instructional materials to guide them (Dare et al., 2018; Osman & Saat, 2014; Stohlmann et al., 2012). The problem is further compounded because existing curricular materials in many countries are not designed to encourage subject integration (Dare et al., 2018; English, 2016). Previous literature has indicated that teaching and learning using STEM-based instructional modules improves students' achievement in science (Hiong & Kamisah, 2015; Rasul, Rauf, Mansor, & Affandi, 2017; Yasin, Amin, & Hin, 2018). The quest to improve student learning outcomes, integrated STEM-based modules has been developed in many countries using several approaches and context as highlighted in the next section.

### **Integrated STEM Education Module Based on the 5E Model**

The review of relevant literature on the development of integrated STEM education modules show that several modules have been developed based on the 5E instructional context (Dass, 2015; Khalil & Osman, 2017; Osman, Hiong, & Vebrianto, 2013; Yasin et al., 2018). Yasin et al. (2018) developed a Malaysian (M)-Biotech-STEM (MBS) module for biotechnology learning among secondary school students. The instructional phases were based on the 5E; engagement, exploration, explanation, elaboration, and evaluation learning model. They believed that 5E models align with STEM principles and design-based learning (Yasin et al., 2018). Data was collected using an achievement test and 21st-century skills questionnaires. The findings indicated that the module improved students' achievement in biotechnology and enhanced students' 21st-century skills.

Similarly, Hiong and Kamisah (2015) developed a Biology, Technology, Engineering, and Mathematics (BTEM) module. The instructional was designed to help students learn nutrition in biology and acquire 21st-century skills among secondary school students in Malaysia. The activities in the module were developed based on the 5E model, and the instructional approach in the module was based on inquiry and problem-based learning.

These modules provided a guide for this study. However, the elements that will scaffold the development of the 21st-century skills were not reported in these modules. The studies failed to establish whether the 5E was explicitly integrated where students learn content matter through the 5E phases or implicitly integrated, meaning that science content was taught separately and then the 5E model was introduced as an add-on to solve the problem. In this present study, the engineering design process was explicitly integrated.

### **Integrated STEM Education Module Based on Project-based Learning**

Gleaning from literature has also shown that integrated STEM education instructional materials have been produced using project-based learning. In an integrated STEM module developed by Goovaerts, De Cock, Struyven, and Dehaene (2018), it involved a project where students were required to build a house fitted with sun boiler with the integration of Mathematics and physics. The module was found to increase students' motivation towards learning because the module engaged the students actively in exploring the instructional content that included gas laws, energy, geometry and quadratic equation, and the application of these content to carry out the project. The validity and reliability of this module were not reported. Similarly, Basuki, Besari, Agata, and Hasyim (2018) designed and implement STEM module to enhance middle school students' learning outcomes. The module was based on project-based learning which consisted of five tasks and lasted for a year. The robotic project was employed to integrate STEM which provided the opportunity for students to link knowledge gained in the classroom to real-life problem-solving. The module was found to enhance students' abstract thinking and learning engagement. Students engagement in project-based learning in this module provided the opportunity for students to explain, demonstrate and apply their knowledge of science and mathematics to design the project.

This study adopted the engineering design process as a context for students to integrate science and mathematics concept to solve an open-ended problem. Research studies have documented the advantage of secondary school students participating in the engineering design process to include

improved learning outcomes and positive attitudes towards STEM subjects (Shahali, Halim, Rasul, Osman, & Zulkifeli, 2016; Wendell & Rogers, 2013). A five-phased engineering design process was adopted (English & King, 2015; Rauf, Rasul, Sathasivam, & Rahim, 2017). The elements embedded in the instructional materials engage learners' higher order cognitive skills and enhance meaningful learning were minds-on activities, hands-on activities, divergent questioning, open-ended problem and inquiry.

### **Instructional Content**

The choice of genetics as an instructional content was chosen after extensive review of related literature which indicated that globally students have learning difficulties in genetics for decades (Agboghoroma & Oyovwi, 2015; Atilla, 2012; Lewis & Wood-Robinson, 2000; Mills Shaw, Van Horne, Zhang, & Boughman, 2008; Williams, Montgomery, & Manokore, 2012). Learning difficulties of genetics are attributed to its multidisciplinary and abstract nature (Agboghoroma & Oyovwi, 2015; Atilla, 2012). Given this, students' achievement in genetics has not been impressive (Danmole & Lameed, 2014). Therefore, a multidisciplinary approach such as integrated STEM approach could promote the meaningful learning of genetics. In this study, iSTEMim integrated the principles of 5E and project-based learning, as reviewed in the previous section. It is hoped that the completed instructional material will provide the opportunity for students' active engagement through defining problem, generation of ideas and application of science and mathematics knowledge to solve an ill-structured problem and in the process engage in meaningful learning. Primarily, the focus of this paper is on the preparation and validation of integrated STEM instructional material (iSTEMim) for genetic instruction among Year 11 science students.

### **RESEARCH QUESTIONS**

The following research questions guided the study:

1. Is iSTEMim reliable and appropriate in learning genetics for Year 11 science students?
2. Is there any significant mean difference between Year 11 science students who learn using iSTEMim and those who learn with the traditional method in genetic achievement?

### **RESEARCH METHODOLOGY**

This study adopted a design and development research for the preparation of iSTEMim while pre-test and post-test control group design was used to test the effects of the instructional material on students' achievement.

#### **Sample**

The sample employed to determine the validity and reliability of iSTEMim during the development phase; ten science education experts were used to validate the instructional material; six of these experts were from the university from the rank of senior lecturers and with more than ten years of teaching and research experience. The remaining four experts were senior science teachers at the secondary school with more than fifteen years' experience. This sample size concurs with Okoli and Pawlowski (2004) who highlighted that ten to eighteen experts are adequate for evaluating an instrument to established experts' consensus.

Thirty-two (18 males and 15 females) Year 11 science students were used to determine the reliability of the iSTEMim. This sample size is supported by Chua (2011) who reported that 30 respondents are adequate to evaluate the consistency of a developed instructional instrument.

During the implementation phase, a summative evaluation of the developed iSTEMim was employed to determine its effects on students' learning and to establish whether the goal of the iSTEMim is achieved. Two schools were randomly selected from Minna, Niger State, Nigeria and randomly allocated to the iSTEMim (experimental) and traditional group (control). In both schools, Year 11

science students were randomly selected. There were thirty students in the experimental group and thirty-two in the control group.

### Preparation of the iSTEMim

Review of the current literature shows there are important factors to be considered in preparing a quality integrated STEM-based instructional environment. These factors are an engaging context that will motivate the students, present the students with an engineering design problem and opportunity for the students to explore learning content (Moore et al., 2014; Walker, Moore, Guzey, & Sorge, 2018). Others are the application of mathematics and science to solve the problem, evidence-based thinking and teamwork (Moore et al., 2014). There are also communication of findings and explicit integration of the engineering design process (Crotty et al., 2017; Mathis, Siverling, Moore, Douglas, & Guzey, 2018). These elements were taken into consideration in the development of the instructional material. For example, the engaging context in this study is a problem scenario;

*A client from a rural area where moth insects are traditionally considered important and add to the aesthetic nature of the environment, but human activities have affected these insects. Your group is contracted to develop a unique moth insect for an exhibition. The model produce should be good, and useful to society to persuade the client to invest.*

This scenario is engaging because it is a real-world scenario which is relevant to the students' real-life and it is an open-ended problem that will require the application of science and mathematics concepts.

The descriptive phase of this research detailed how the instructional materials were developed. The study adopted the framework of the ADDIE model to achieve the goal of the study (Dick, Carey, & Carey, 2001; Fadzil & Saat, 2019). The ADDIE model is an organised way to design and develop teaching and learning materials. It provides the latitude to integrate instructional activities, strategies, assessment instruments and guidelines. This study involves the five stages of ADDIE; (i) Analysis, (ii) Design, (iii) Development, (iv) Implementation and (v) Evaluation.

### Analysis

This is the first phase which involved the gathering of relevant information to identify the needs for the development of instructional material and the target audience. This was achieved through analysis of curriculum content and textbooks as well as through literature. Science education teachers were also interviewed to provide relevant information on the need for preparing the iSTEMim. Findings from the interviews with teachers showed that they lacked the required expertise to implement an integrated STEM approach, and there were no instructional materials to guide them, as stated in the following excerpt:

*Integrated STEM approach sounds interesting, but I cannot seem to figure out how to implement because there are no textbooks or instructional materials for guidance. All I have now are recommended books, a scheme of work and charts for a few topics. (Asonum 16/01/2018)*

The teachers' responses also indicated that genetics is a difficult concept to teach. This concurs with the earlier findings of Atilla (2012) who reported teaching and learning difficulties in genetics because of its multidisciplinary nature. Policy document stipulated that science should be taught in an integrated manner (FRN, 2004, P32). However, the findings from the analysis of biology textbooks and syllabus showed that textbooks are subject-based and are written in isolation. Therefore, available instructional materials are not in line with the policy statement as indicated above. Given the preceding, the need to develop the iSTEMim was established.

**Design**

This phase involved the identification of the instructional components. First, the learning objectives are identified. Secondly based on the objectives other components are established; instructional elements, iSTEMim iterative phases (learning context), and tasks. At this phase, the elements of each component were proposed and a draft copy of the instructional material produced. The draft copy of the instructional material was subjected to formative evaluation in the next phase.

**Development**

The proposed iSTEMim went through two rounds of experts’ consensus survey. Based on the findings from experts’ consensus, the different components of the module were established. The comments and suggestion from the experts were used to modify the instruction material. Example of experts’ comments and observation are highlighted in Table 1.

Table 1  
*Experts’ Suggestions and Researchers Action*

Section	Experts comments and suggestion	Researchers Action
Content	Consider including some websites and reference materials that will guide the students to specific valuable information.	several textbooks were recommended, and websites included to guide students during the generation of ideas (refer to the appendix)
Instructional phases	All the instructional phases are quite clear in execution except for generation of ideas the steps are difficult to understand	The generation of ideas have been rearranged logically; ideas on genetic content knowledge; ideas on genetic engineering procedures, and proposal on how to implement the ideas to solve the problem

The instructional material was sent for the second evaluation where there was experts’ consensus on the components of the iSTEMim for learning genetics. Instructional elements that were agreed upon by the experts to be embedded in the instructional material included an open-ended problem, real-world task, hands-on activities, minds-on activities, inquiry and questioning. The instructional context is adopted engineering design process.

The phases adopted based on experts’ consensus were engaging the problem, generate ideas, design solution, evaluate and improve, and communicate findings as highlighted in figure 1.

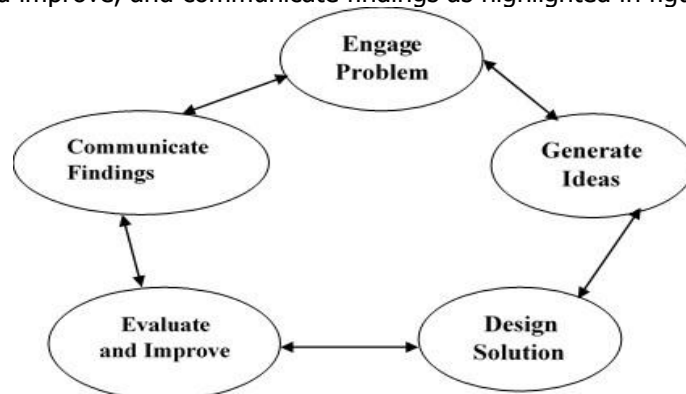


Figure 1. Engineering Design Process (adapted from English and King, 2015)

Figure 1 shows that the first phase is to get students to engage the problem where students are asked to analyse the problem scenario into essential components, to state some constraints of solving the problem and highlight the goal of the problem. This phase engages the students' cognitive skills of analysis, deduction and also stimulate their curiosity (Dass, 2015). In the second phase where students are required to generate ideas to solve the problem. Aspects of science and mathematics concepts and principles that are to be applied to solve the problem. They further generate ideas and procedures to be used to solve the problem. During the generation of ideas, the students present their thoughts or ideas and offer explanations for their opinions and members of the group can prompt one another for justification of their views. The entire group assessed each idea or claim and drew an early conclusion, thus engaging in evaluation and inference sub-skills of critical thinking. In this phase, the students generate ideas individually and meet in a group to brainstorm. In the third phase, students are expected to sketch their solution and translate the solution into a 2D or 3D. The development of 2D or 3D sketches engages students in hands-on and minds-on activities and externalising their thinking (Wu & Rau, 2019). The solution could be a prototype, product or a process since we are dealing with biological phenomena. The students evaluate their solution, improve their solution and finally communicate their findings.

### **Overview of the iSTEMim**

The iSTEMim provides the students with the opportunity to explore learning content, collaborate and apply the knowledge of the learning content to solve real-life problems. The iSTEMim has three open-ended challenges or tasks, in one of the tasks, the students were required to design a unique insect for a client. In order to do so, students would need to master and apply the knowledge of genetic; principles of dominance, recessive, phenotype, and probability. This would be carried out through the use of a five-phased iterative process as highlighted above. To enhance students' engagement, design worksheets were provided as learning tools to guide the students. An example of a learning task using iSTEMim is attached as Appendix 1.

### **Implementation and Evaluation**

The two final stages of ADDIE would be discussed here. The teachers were trained as facilitators during the implementation of the instructional material. The validated module was implemented to determine its effects on students' achievement. The experimental group learned using the iSTEMim while the control group learned using the teacher-centred method of instruction using the textbooks and notes. The data was collected using the genetic achievement test which was adopted from the West African Senior Secondary School Certificate (WASSCE). The genetic achievement test was made up of forty objective questions from Mendelian laws, genetic terminology and genetic probability subsections of genetics. The reliability of the subsections of the test was between 0.71 to 0.74. These values were considered acceptable (Sekaran & Bougie, 2010). The instrument was administered as a pre and post-test. To test the reliability of iSTEMim, four-point Likert type questionnaires; Strongly agree (4), Agree (3), disagree (2), and Strongly disagree (1) were used. The reliability of the questionnaires was 0.72 using the Cronbach's Alpha which was consider suitable. A reliability value of 0.60 is adequate for instruments developed in the field of education and social science (Sekaran & Bougie, 2010). The study lasted for four weeks; in the first week, the pre-test was administered, and orientation on how to use the iSTEMim was given. The intervention began in the second week, and the post-test was collected after the intervention in the fourth week.

### **Data Analysis**

Rusell (1974) reported that a module or instruction material is certified for use when its validity and reliability has been established and found suitable. Therefore, there was a need to determine the validity and reliability of iSTEMim. The data generated from questionnaires were analysed using content validity. Cronbach's Alpha was used to determine the reliability of the module while pre and post-test data were analysed using t-test.

**Ethical Consideration**

Permission was obtained from the school management, students and teachers to conduct this research. The consent of the students was sought using consent letters highlighting the extent of their involvement in the study. The aim of the study was explained to the participants and the information collected from the students will be kept confidential and use strictly for this research. The secondary school students were told that they could withdraw from the study at any time without any consequences.

**RESULTS**

**Content Validity**

Content validity in this study was determined by calculating the content validity index (CVI) (Sidek & Jamaludin, 2005) cited in Kasim and Ahmad (2018). This is an inert-rater consensus index which is mostly used to estimate the percentage of agreement among experts (Zamanzadeh et al., 2015). This is achieved by computing the average experts' consensus on an item (I-CVI), item accepted are denoted as (1) this implies that I-CVI value should be .78 and above as good content validity while items not accepted as (0 that is below .78 when the number of experts is three and above (Polit, Beck, & Owen, 2007; Zamanzadeh et al., 2015). The overall content validity index (S-CVI) is .80 and above. The result of Content validity is as presented in Table 2.

Table 2  
*Expert consensus on the validation of iSTEMim*

Component	Item	Relevance	Not Relevant	I-CVI	Remarks
iSTEMim Presentation	The arrangement of the instructional material was satisfactory	10	0	1.00	Satisfactory
	The clarity of the images was good and attractive	8	2	.80	Satisfactory
	Font size and type, and colours promote legibility of the instructional material	10	0	1.00	Satisfactory
	The English language used is appropriate	9	1	.90	Satisfactory
	The instructional material is user-friendly	10	0	1.00	Satisfactory
STEM Approach	Driving questions were clear and understandable	10	0	1.00	Satisfactory
	The iSTEM phases were logically arranged	10	0	1.00	Satisfactory
	The instructional material encourages learning by doing and collaboration	10	0	1.00	Satisfactory
	Engineering provided the context for science and mathematics integration.	10	0	1.00	Satisfactory
	The instructional material has real-world and open-ended problems.	10	0	1.00	Satisfactory
The goal of the instructional material	The instructional material could enhance students' genetic achievement	10	0	1.00	Satisfactory
	Enhanced learners' engagement	10	0	1.00	Satisfactory

Activities	and active participation The tasks were challenging and design-based	8	2	.80	Satisfactory
	The activities engage students' higher cognitive abilities	10	0	1.00	Satisfactory
Target Population	The instructional material is suitable for the target population	10	0	1.00	Satisfactory
Time Allocation	Adequate time for the activities was allocated	10	0	1.00	Satisfactory
S-CVI				0.967	

Table 2 shows that all the items in the questionnaires have an I-CVI of .80 and above which is higher than the minimum value of I-CVI .78. The S-CVI was .96, higher than the minimum value of .80. This indicates that there was a consensus among the ten science education experts that the iSTEMim has good content validity (Polit et al., 2007).

**Reliability**

To determine the reliability of the iSTEMim, Cronbach's Alpha was used. The results indicated a reliability coefficient of .80 which is considered acceptable. The findings agree with the earlier reports that the Cronbach's Alpha reliability value of 0.60 and above is adequate for instruments developed in the field of education and social science (Hair, Black, Babin, & Anderson, 2010; Sekaran & Bougie, 2010).

**The effects of iSTEMim**

The within-group comparison was made to determine whether there is a significant mean difference between pre-test and post-test. Paired sample t-test was employed, and the result is as presented in Table 3.

Table 3  
*Paired Sample t-test of within-group Comparison*

Dimension	Group	Pre-test Mean ± SD	Post-test Mean ± SD	Post-pre Test	t-value	df	p-value	d <sup>2</sup>
Genetic Laws	iSTEMim	10.53±2.20	14.27±4.47	3.74	-3.95	29	.00	1.06
	Traditional	11.16±2.52	11.63±3.27	.47	-.72	31	.47	0.16
Terminology	iSTEMim	9.93±2.95	12.23±3.70	2.30	-3.22	29	.01	0.68
	Traditional	10.41±2.61	10.69±3.30	.28	-.40	31	.69	0.09
Probability	iSTEMim	10.47±2.40	13.33±2.85	2.86	-4.10	29	.00	1.08
	Traditional	10.91±1.84	11.03±3.25	.12	-.17	31	.86	0.04
Overall Score	iSTEMim	30.93±6.06	39.83±3.10	8.90	-5.39	29	.00	1.84
	Traditional	32.48±5.94	33.35±3.10	1.05	-.74	31	.46	0.18

Table 3 shows that the pre-test of genetic laws subsection for students who learn with iSTEMim ( $M=10.53, SD=2.20$ ), while the post-test ( $M=14.27, SD=4.47$ ). The dependent sample t-test shows that the mean difference of within-group comparison was significant  $t(29) = -3.95, p(.00) < .05$ . The magnitude of the effect size using Cohen's d is large ( $d^2 = 1.06$ ) (Cohen, 1988). On the other hand, the pre-test, post-test result of the traditional group in genetic laws dimension was ( $M=11.16, SD=2.52$ ) and ( $M=11.63, SD=3.27$ ) respectively. The dependent sample t-test shows no significant difference  $t(31) = -.71, p(.47) > .05$  and the effect is small ( $d^2 = 0.16$ ).



The result of the group that learn with iSTEMim in the terminology dimension of genetics shows the pre-test, and the post-test result is ( $M=9.93$ , and  $SD=2.95$ ) and ( $M=12.23$ , and  $SD=3.70$ ) respectively. The dependent sample t-test shows a significant mean difference between the pre-test and post-test terminology dimension  $t(29) = -3.22, p(.01) < .05$ . The effect size is medium ( $d^2=0.68$ ). While the traditional group pre-test and the post-test result were ( $M=10.41$ ,  $SD=2.61$ ) and ( $M=10.69$ ,  $SD=3.30$ ) respectively. Paired t-test result shows there is no significant mean differences of within-group contrast  $t(31) = -.40, p(.47) > .05$ . The effect size is small ( $d^2 = 0.09$ ).

The pre-test and post-test result of the diSTEMim group in the genetic probability dimension are ( $M= 10.47$ ,  $SD=2.20$ ) and ( $M= 13.33$ ,  $SD=2.85$ ) respectively. The paired sample t-test shows there is a significant mean difference of within-group contrast  $t(29)= -4.10, p(.00)<.05$ . The effect size is large ( $d^2 =1.08$ ). Similarly, the pre-test and the post-test result of the traditional group shows ( $M= 10.91$ ,  $SD=1.84$ ) and ( $M=11.03$ ,  $SD=3.25$ ). The mean difference between the pre-test and post-test was not significant;  $t(31)= -.17, p(.86)>.05$ . The effect size is small ( $d^2 =0.04$ ).

The pre-test, and post-test findings of the overall genetic score of iSTEMim group shows ( $M=30.93$ ,  $SD= 6.06$ ) and ( $M=39.83$ ,  $SD=3.10$ ) respectively. The paired sample t-test was associated with a significant difference  $t(29)=-5.39, p(.00) <.05$ . The effect size was large ( $d^2 =1.84$ ). This implies that iSTEMim has a large effect on enhancing students' genetic learning and achievement. The tradition group show the pre-test ( $M= 32.48$ ,  $SD=5.94$ ) and post-test ( $M=33.35$ ,  $SD=3.10$ ). The mean difference was not significant.  $t(31)= -.74, p(.46)>.05$ . The magnitude of the effect size was small ( $d^2=0.18$ ). In view of the effect size of the overall genetic score, it implies that the iSTEMim was more effective than the traditional method.

Given the preceding, an independent t-test was carried out to compare the post-test scores between the iSTEMim group and the traditional group. The result is as presented in Table 4.

Table 4  
*Between-Group Comparison of Genetic Achievement*

Dimension	Group	Mean	SD	df	t-value	p-value
Genetic Laws	iSTEMim	14.27	4.47	60	2.66	.01
	Traditional	11.63	3.27			
Terminology	iSTEMim	12.23	2.66	60	-.59	.55
	Traditional	10.69	3.30			
Probability	iSTEMim	13.33	2.85	60	2.95	.00
	Traditional	11.03	3.25			
Overall Score	iSTEMim	39.83	7.18	60	3.23	00
	Traditional	33.35	3.09			

Table 4 shows the result of the between-group comparison of the iSTEMim group and traditional group. There was a significant mean difference between the iSTEMim and the traditional group in genetic laws subset  $t(60)= 2.66, p(.01) <.05$ . Indicating the iSTEMim group ( $M=14.27$ ) perform better than the traditional group ( $M=11.63$ ). In the terminology subsection, there was no significant difference between the two groups in the terminology subsection of genetics  $t(60)= -.59, p(.55) > .05$ . However, the iSTEMim group ( $M=12.23$ ) perform better than the traditional group ( $M=10.69$ ). There was a significant mean difference between the iSTEMim and the conventional group in probability dimension of genetics  $t(60)= 2.95, p(.00) <.05$ . Indicating the iSTEMim group ( $M=13.33$ ) perform better than the traditional group ( $M=11.03$ ). The overall genetic score shows a significant mean difference between the group that learn with iSTEMim and the traditional group  $t(60)= 3.23, p(.00) <.05$  — indicating that the iSTEMim group ( $M=39.83$ ) perform better than the traditional group ( $M=33.35$ ).

## DISCUSSION

The purpose of this study is to prepare an integrated STEM instructional material (iSTEMim) for the teaching and learning of genetics and determining the validity, and reliability as well as its effects on secondary school students' genetic learning. The findings show that the validity of iSTEMim was accepted and have good content validity. The internal consistency of the instructional material using Cronbach alpha was satisfactory and acceptable as indicated in the findings. This result agrees with the earlier reports that the Cronbach Alpha reliability value of 0.60 is adequate for instruments developed in the field of education and social science (Hair et al., 2010; Sekaran & Bougie, 2010). This study seems to demonstrate that developing STEM instructional material based on engineering design challenge which offers the opportunity to integrate science and mathematics could provide valid and reliable instructional material (Mathis et al., 2018; Moore et al., 2014).

The findings also show that those students that learn using iSTEMim perform significantly higher in the post-test compared to the pre-test in all the dimension of genetic achievement (genetic laws, terminology, and probability) than the traditional group. The learner-centred nature of the iSTEMim provided the opportunity for students to be accountable for their learning which help students engage in self-assessment of their ideas. Williams (2018) reported that students' accountability enhances their engagement and meaningful learning. Similarly, iSTEMim provided a learning environment that allows students to work collaboratively to learn concepts, share ideas, and make decisions based on group agreement. During the collaboration, students present their ideas and justify while other members ask questions for clarity and explanation. These mental processes could scaffold students understanding of genetics. This concurs with Ah-Nam and Osman (2017) who observed that peer interaction in the learning process could serve as a mental scaffold that would deepen students' understanding.

The elements embedded in iSTEMim such as questioning, hands-on activities, minds-on activities and communication of findings could have enhanced students' active engagement and learning experience of genetics. This concurs with the finding of Kuo, Tuan, and Chin (2018) who study the effects of inquiry-based instruction on students' motivation towards learning science among 8<sup>th</sup> graders. The approach was characterised active engagement; proposing questions, formulating hypotheses, designing experiment, drawing conclusion and communication of findings. The findings show that students learning outcomes of science were enhanced.

The between-group comparison indicated that the iSTEMim group perform significantly better than their counterpart in the traditional group as reported in the results. This implies that iSTEMim which is valid and reliable seem to be effective in enhancing students' achievement in genetics. This finding also concurs with several scholars who reported that teaching and learning using STEM-based instructional modules improves students' achievement in science (Hiong & Kamisah, 2015; Rasul et al., 2017; Yasin et al., 2018).

## CONCLUSIONS

This study contributed to the current literature on the preparation or development of STEM-based instructional materials for science instruction. Given the findings, it was concluded that the iSTEMim has good content validity and is reliable. The iSTEMim was also effective in promoting or fostering secondary school students' learning of genetics. Thus, this study may provide a guide for teachers to develop a STEM instructional module for classroom instruction, especially at the secondary school level. The iSTEMim was developed to focus on teaching and learning genetics. Therefore, further studies could focus on other science concepts or topics.

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## Appendix 1

### An example of a task using iSTEMim

**Instructions:** In the learning process you (students) are expected to play the role of a bioengineer or genetic engineer. Apply the principles of science (genetic laws and principles) mathematics thinking (probability, and algebraic thinking) to solve a problem. The solution should benefit the present society and future generations. Students are to generate ideas individually and meet in their respective group to brainstorm at the end of each phase. Use the worksheets provided for each phase.

**Problem scenario:** *A client from a rural area where moth insects are traditionally considered essential and add to the aesthetic nature of the environment, but human activities such as the use of insecticides has affected these insects. Your group is contacted to engineer a unique moth insect for an exhibition. Since genetic engineering is costly and requires enormous sums of money, the model produce should be good, and useful to society to persuade the client to invest.*

Firstly, the students use the KWLH worksheet to activate their prior knowledge and engage in reflection on the problem scenario by finding answers to the following questions.

What do you **know** about the problem? **What** do you need to know about the problem?  
**How** do I proceed with the problem? How can we **apply** the findings to our daily lives?

Table 1  
*The iSTEMim Learning Task*

Phases	Activity
<b>Engaging the problem</b>	What are the components of the problem? How will you describe your unique insect? Highlight the constraint of the problem. Highlight the goal of the problem
<b>Generation of ideas</b>	Generate ideas on Mendelian first law; <b>Driving question;</b> If both parents of an organism are white in their appearance, is the appearance of a new trait in the offspring feasible? <b>Resources:</b> <a href="https://www.toppr.com/guides/biology/principles-of-inheritance-and-variations/laws-of-inheritance/">https://www.toppr.com/guides/biology/principles-of-inheritance-and-variations/laws-of-inheritance/</a> <a href="https://www.youtube.com/watch?v=a5GMp9BPEkA">https://www.youtube.com/watch?v=a5GMp9BPEkA</a> Biology textbooks
	<b>Reflection Questions;</b> Given the information gathered from different sources answer the following questions; <ul style="list-style-type: none"> <li>• Who was Gregor Mendel? Highlights the genetic terminologies you discovered</li> <li>• What were the dominant characters? Also, why</li> <li>• Explain why some traits were not visible in some generation</li> </ul>
	<b>Opportunity to Demonstrate Monohybrid Inheritance:</b> the materials needed are two coins. The student records the contribution of a parent's alleles to form the offspring allele. Toss the coin 20 times and record your result in a table.

**Phases**

**Activity**


**Statistics;** From the data generated calculate the genotypic and phenotypic ratios, the percentage of the dominant and recessive trait.

The Law of Dominance



Examine the picture above, given Mendel's law of segregation, determine which of the two is the male and answer the following questions:

- What will be the possible colour of the chick when it is hatch and why?
- What will be the genotype of the parents and the offspring?
- How will you describe the colour that manifests physically and the one that did not manifest?

Mendel's Second law of heredity

Biology textbooks

<https://byjus.com/biology/law-independent-assortment/>

<https://www.brightstorm.com/science/biology/mendelian-genetics/law-of-independent-assortment/>

**Designing solution**

- a Based on the goal highlighted in phase 1 (unique moth insect) map out the parents' traits that will produce the unique organism  
Sketch the diagram of your unique moth insect

**Constructing the model of the moth insect**

The students will determine the genotype and phenotype of the offspring using the parent genotype and phenotype information and highlight the relevant materials to be used.

**Phases**

**Activity**

Trait	Allele from the parent male	Allele from the parent female	Offspring genotype	Offspring Phenotype	Materials
Body segments					
Wings					
Wings colour					
Antennae style					
Colour of legs					
Pairs of legs					
Eyes colour					

Translate the design into a 3d model by building the model of the offspring based on the information in the table using local materials

<b>Evaluation and improved</b>	Has the goal of the design achieved? Why? Alternatively, why not? What are the ways to improve the design?
<b>Communicate findings</b>	Each group will present their findings of the entire process and their outcome to the whole class