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Exploring Design Principles for STEAM Learning Activities Development by Science and Technology Teachers[1]

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Abstract

This study explored the design principles of science, technology, engineering, arts, and mathematics (STEAM) learning activities developed by science and technology teachers for classroom practice. Through a qualitative approach, interpretive paradigm, and design-based research, 12 Bachelor of Education honours degree students were conveniently sampled. Data were collected by means of reflections and development of learning materials through the analysis, design, development, implementation, and evaluation (ADDIE) model. The study followed the design-based research stages of needs analysis, development, testing, and reflection to produce design principles, and it was underpinned by the learning theory of constructionism. The findings showcase the design principles to include design thinking, finding solutions for learning problems, creativity, and innovation applied to instructional design. The study recommends the use of design thinking pedagogies in developing teacher knowledge on STEAM classroom practice.

Keywords: 21st century skills development, design thinking, STEAM material design and development

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Introduction and Background

Science, technology, engineering, and mathematics (STEM) education prepares learners for life by equipping them with the important 21st century skills. There are widespread beliefs that the fastest growing professions require STEM knowledge and skills (du Plessis, 2018). Nadelson and Seifert (2017) indicated that the 21st century is undergoing a synthesis age in which new professions are emerging. Accordingly, the teaching and learning of STEM in the classrooms must be relevant to the learners'

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everyday lives and their career aspirations. The achievement of STEM literacies such as creativity, innovation, critical thinking, and problem solving is an important goal in the 21st century. STEM education develops innovative talent in citizens to meet the economic development, environmental, and social well-being needs of the 21st century (Wang et al., 2018).

Nadelson and Seifert (2017) expanded the list of the 21st century skills to include identifying/recognising/classifying, design/experimentation, modelling/simulation, repurposing and restructuring, inventing and creating, theorising/critiquing and validation, and more importantly, innovation. The STEM subjects are critical for the development of these skills. However, the achievement of these STEM skills has been elusive. One of the strategies used to enhance the development of STEM skills in the classroom is embracing holistic and discipline-integrative approaches (Bartels et al., 2019). By implementing STEM education, there is a recognition that life problems and real-life situations are multidisciplinary (Bybee, 2013). There is a call to shift away from instructional strategies that do not bring out the relevance of teaching and learning through the implementation of STEM education. One way of making STEM education relevant is the integration of the arts—resulting in a shift to science, technology, engineering, arts, and mathematics (STEAM) education.

Quigley and Herro (2016) described STEAM education as a modified curriculum, and pointed out that there is a limited scope of studies on the actual implementation of STEAM in the classrooms. The learning of STEAM is lauded for its potential to enhance development of the 21st-century skills of creativity and innovation. In their review of literature, Perignat and Katz-Buonincontro (2019) concluded that there are various interpretations of the arts, and that there are no specific outcomes for the related skills of creativity, problem solving, and arts education. It can be argued that integrating the arts into STEM education requires teachers to display creativity and innovative skills, and to engage in critical thinking and problem solving as they design and develop learning materials. For teachers to teach these skills, they have to be competent in those skills. If the teachers do not possess knowledge of the aforementioned 21st-century skills, it may be difficult for them to teach these in their classrooms. In support of that argument, Jho and Song (2016) observed in their study of a successful case of STEAM implementation in two Korean schools, that the teachers applied open-mindedness and innovativeness. However, Anisimova et al. (2020) have argued that traditional ways of preparing teachers may not help them to teach STEAM effectively in the classroom, and thus underscored the importance employing innovative strategies. This paper problematises science and technology teachers using creativity, innovation, and problem-solving skills to facilitate STEAM learning activities for learners. Accordingly, the study explored the design and development of STEAM learning activities by science and technology teachers enrolled in a Bachelor of Education (BEd) honours degree programme at a South African university. The study contributes insights on how science and technology teachers use innovativeness, creativity, and problem-solving skills to develop STEAM learning activities. Therefore, the research question guiding this study is: “How do science and technology teachers use design principles for STEAM learning activities for classroom practice?”

Related Literature on Designing STEAM Learning Activities

Most school curricula use a multidisciplinary approach for the teaching of STEAM subjects, in which the constituent subjects are taught separately. Therefore, the curriculum innovation of STEAM is not packaged as a stand-alone subject in many school curricula but is taught through integration approaches in subjects such as science and technology, science, mathematics, and engineering. The result is that teachers must go out of their way to plan for the integration of arts into the subjects they teach. Hawari and Noor (2020) confirmed that one of the challenges in the implementation of STEAM education pertains to curriculum demands. As McDonald et al. (2020) pointed out, the implementation of STEAM education is impeded by the use of traditional teaching strategies, and the placement of the STEAM constituent subjects in hierarchies that lead to the neglect of some.

Another challenge faced by teachers is that STEAM learning activities are not evident and readily available in the curriculum materials and textbooks. Keane and Keane (2016) asserted that teachers must engage in design thinking to come up with the relevant learning materials to ensure that STEAM is taught in schools. And Henriksen (2017) said teachers need to be creative in order to come up with STEAM learning activities. In support of Keane and Keane (2016), Henriksen (2017) also suggested that teachers employ creativity skills and engage in design thinking to develop STEAM learning materials. However, Anisimova et al. (2020) argued that the teachers must first be trained in design and research competencies for them to be able to develop materials and implement STEAM curriculum innovation. That argument makes sense because it would be unfair to ask teachers to implement something for which they are not competent.

Engaging learners in STEAM also involves exposing learners to design thinking (Ozkan & Umdu Topsakal, 2021). Design thinking in STEAM teaching enables learners to be innovative and creative as shown by Ozkan and Umdu Topsakal (2021) who used STEAM learning activities in which learners were engaged in design thinking to develop creative thinking skills. What can be deduced from the findings by Henriksen (2017) and Ozkan and Umdu Topsakal (2021) is that in the implementation of STEAM, design thinking is crucial for the development of creativity skills for learners. And teachers must be competent in design thinking and creativity because these skills are needed in the development of STEAM learning materials.

STEAM education can be combined with other instructional strategies to enhance learning outcomes. Baidal-Bustamante et al. (2023) investigated a STEAM and problem-based approach to teach the science topic of Pascal's principle using an experimental research design, and they observed that learners in the experimental group were more motivated to complete the tasks and performed better than the learners in the control group. Similarly, Hawari and Noor (2020) used problem-based learning emphasised an artistic way of completing a STEAM project, and found that the learners developed skills of collaboration, communication, and problem solving. In a study by Temiz and Çevik (2023) in which five STEAM projects were given to 5–6-year-old learners, it was observed they came up with designs and created their own products. Those project activities required enough time for engagement and materials necessary for creating product.

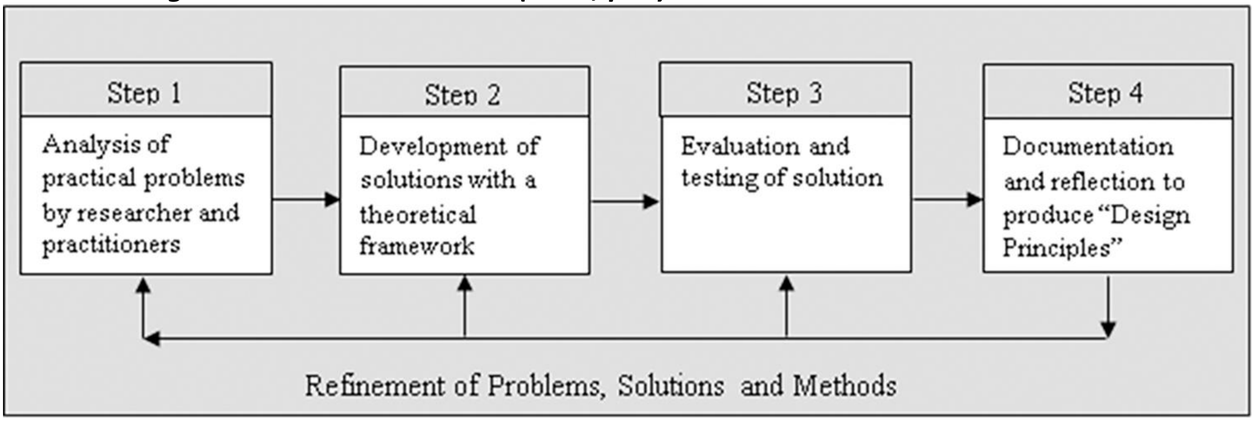
Theoretical Framework

This study is underpinned by the learning theory of constructionism, in which the focus is on the meanings generated by the students who participated in the study—rather than focusing on their shortcomings. Kynigos (2015) asserted that constructionism is also considered a theory of design. Ackermann (2001) explained Papert's constructionism by comparing it with Piaget's constructivism, saying the latter provides insights on what humans can do at different stages of development, and the former puts the humans at the centre of learning by allowing them to make things while they are learning. Parpet's constructionism theory is used in this study, based on its tenets of learner-centredness, allowing the learner to make things, enabling self-directed learning, and learning to learn (Ackermann, 2001). Constructionism was used as a lens to make meaning of the design principles used by BEd honours students to develop STEAM learning activities for science and technology classrooms. Constructionism puts emphasis on learning by doing and, in this case, the participating students were given an opportunity to engage in STEAM activities design, and the development of materials through the ADDIE (analysis, design, development, implementation, and evaluation) model of instructional design. The ADDIE model has been lauded for providing structure and guiding instructional design (Budoya et al., 2019; Hess & Greer, 2016). The ADDIE model of instructional design was useful in this study because, according to researchers such as Keane and Keane (2016) and Henriksen (2017), teachers are able to implement STEAM education in the classrooms if they can design the learning materials.

Research Methods and Data Analysis

The study used a qualitative approach and interpretive paradigm based on Reeves' (2000) design-based research model (Figure 1).

Figure 1
Reeves' Design-Based Research Model (2000, p. 9)



The model was used to explore the perspectives of 12 BEd honours students at a South African university on teaching STEAM in school science and technology classrooms. The students were all science and technology teachers with teaching experience ranging from 1–5 years. These students were purposely and conveniently selected for being teachers of science or technology participating in the BEd honours degree programme. Their names were anonymised as BHS1–BHS12 (BEd honours degree Student 1 to BEd honours Student 12. They consisted of seven men and five women; four taught in primary schools and eight taught in secondary schools. The primary school teachers taught both natural sciences and technology. Of the secondary school teachers, four taught life sciences and four taught physical sciences.

Data Collection Procedures

The qualitative data were collected by means of a STEAM design task consisting of open-ended design prompts and reflections. The design process was guided by the ADDIE process for curriculum design. The first phase of the research, the needs analysis (Reeves, 2000), was based on a review of the BEd honours science and technology subject specialisation course, resulting in the addition of curriculum innovation topics that included STEAM education. In order to assess the needs of the participants, the researcher applied an intervention that entailed four 2-hour sessions to discuss the STEM and STEAM frameworks implemented in school science and technology classrooms. The intervention was in the form of lectures and group discussions. During the discussions, the students reflected on their experiences of facilitating STEAM activities. From the discussions, the researcher noted that not all students were familiar with STEAM integration in the classrooms. This is evidenced by what four of the students said below. BHS10 with 5 years of teaching experience claimed he was only aware of STEM and not STEAM. He said:

> *I did not know what STEAM education was, because I only had an idea of STEM education before—not knowing [that] the integration of art is involved as much as science, technology, and mathematics are integrated.*

That sentiment was shared by BHS11 who said:

> *Above all else, for me, the ability to incorporate the arts into STEM fields is also a big revelation to me about STEAM.*

After the intervention based on STEAM activity integration in the classrooms, BHS7 admitted to learning something new. He said:

> *Prior to the STEAM/STEM activities, my understanding of STEAM education was limited. I primarily associated it with the integration of science, technology, engineering, arts, and mathematics, but I had not explored its practical applications in teaching and learning.*

This unfamiliarity with STEAM was echoed by BHS11 who said:

> *My grasp of STEAM education was minimal. I understood that it was an educational method that merged science, technology, engineering, the arts, and mathematics, but I didn't completely understand how or why these disciplines were linked. I always viewed the arts as different from and inferior to the STEM sciences. Art is creative and not logical, we learned art in school as a subject that had nothing to do with science and inferior to science.*

These students' reflections (collected during the interventions, and which indicated limited experiences and familiarity with STEAM activities) were used to develop learning experiences that were used in the second stage of design-based research (Figure 1). The stage entailed the development of solutions, undergirded by conceptual framework based on constructionism through the ADDIE model of curriculum design and STEAM education. This was followed by an evaluation and testing stage (Figure 1) where the students were given the task of designing learning materials that could be used in their science and technology classrooms. The STEAM activity design task given to the students is displayed in Figure 2.

Figure 2

Design-Based Task to Develop STEAM Teaching and Learning Materials Using the ADDIE Model

Activity: Design-based task to develop STEAM teaching and learning materials using the ADDIE model.
As a science or technology teacher, in this activity, you must use the ADDIE (analysis, design, develop, implement, and evaluate) curriculum design and development model to design and develop steam materials and a lesson plan for your classroom. The table below displays what you must do under each stage of the ADDIE model and your efforts under each criterion will be evaluated based on your creativity, innovativeness, and problem-solving skills.

Stage of curriculum design & development	Tasks to be completed	Rubric to evaluate teacher activities Teacher creativity: Yes/no Teacher innovativeness: Yes/no Teacher problem-solving skills: Yes/no
Analysis	The needs analysis entails identifying a learning problem in your science or technology classroom that can be solved through STEAM education.	Learning problem STEAM solution
Design	Design the learning activity by indicating the STEAM education approach to be used. Include the purpose/outcome of the STEAM learning activity, grade, topic, and instructional strategy(ies).	STEAM education approach STEAM education learning purpose/outcome STEAM topic and instructional strategies
Development	Develop the lesson objectives, content, learning activities, learning materials, the arts component to be integrated, and how.	Lesson objectives Learning activities Learning materials Arts integration
Implementation	Display/exemplification of the teacher and learner activities.	Teacher activities Learner activities
Evaluation	Describe and provide assessment tools that will be given to learners.	Description of the assessment tool The assessment tool

Reflect on how you have been creative and innovative in designing and developing the STEAM learning activity for your learners.
Reflect on your understanding of STEAM education prior to participating in this study.
Reflect on how your participation in this study has changed your understanding of STEAM education if at all. Give reasons.

In the fourth stage of the design-based research (Figure 1), the researcher analysed and reflected on the reflections of the students and the STEAM materials they developed. A mix of directed and inductive content analysis was used to generate categories that were further collapsed into themes. Table 1 is an extract of a code book showing examples of how the data were coded and analysed.

Table1
Code Book Extract Showing Examples of the Data Analysis

Code	Description of code	Example of data	Emerging category
Needs analysis	-Needs analysis for STEAM integration -Challenges encountered when teaching STEAM disciplines	-In all my experience of teaching life sciences in rural areas, learners are deprived the practical part of life sciences. (BHS1)	STEAM activities used to engage learners in hands-on activities
Design of STEAM activities	-Selected topics to be taught -Identification of the arts activities to be used	-I designed activities that are fun and engaging as learners get to explore STEAM materials in completing all the activities. (BHS1)	STEAM activities are engaging and enjoyed by learners
Development of STEAM activities	-Arts-based activities conducted and materials developed by the learners in the classrooms -Arts-based materials used for teaching	Learners will draw a colourful chart of the human respiratory system. Learners will compose and sing the song in front of their peers. (BHS5)	Use of visual arts and music
Implementation of STEAM activities	-Proposed instructional strategies to implement STEAM in the classroom	Learners work in groups to conduct hands-on activities using materials that include balloons, a darkened room, fluorescent lamps, a sink, and running water including computer simulations. (BHS6)	Use of group work and hands-on activities
Evaluation of the STEAM activities through reflection	-BHS reflections of the STEAM material development -Development of learner assessments of the STEAM activities	-Designing STEAM activities helped me to access different ways in which art can be integrated with life sciences. (BHS1)	Teachers become innovative and creative

Further, a summary of the participant students’ profiles and their STEAM activities designs is displayed in Table 2.

Table 2
Summary of Participants' Profiles and STEAM Activity Designs

Student	Teaching experience	Analysis/problem	Design arts	Development/lesson topic	Implementation	Evaluation
BHS1 (female)	1 year	Lack of practical work	Visual arts: posters	Phototropism (secondary science)	Experiments and drawing	Poster presentation
BHS2 (female)	1 year	Lack of practical work	Dance	States of matter (primary science)	Experiments and dance	Group work and oral questioning
BHS3 (female)	1 year	Misconceptions	Visual arts: models & crafts	Earth's rotation (primary science)	Demonstrations and project-based learning	Models
BHS4 (male)	2 years	Misconceptions	Visual arts: drawing	Structure of matter (secondary science)	Virtual reality practical work	Quizzes
BHS5 (male)	1 year	Misconceptions	Song Visual arts: posters, and models	Respiratory system (secondary science)	Demonstrations and project-based learning	Poster presentation and models
BHS6 (male)	1 year	Misconceptions	Visual arts: drawings and videos	Electricity (secondary science)	Demonstrations, hands-on & virtual reality experiments	Drawings and quizzes
BHS7 (male)	1 year	Misconceptions	Visual arts: augmented reality	Earth and beyond (primary science)	Augmented reality field trips	Oral questioning
BHS8 (male)	1 year	Misconceptions	Visual arts: models and virtual reality	Electrical circuits (primary technology)	Project-based learning and virtual reality experiments	Projects
BHS9 (male)	1 year	Misconceptions	Visual arts: videos and models	Newton's laws (secondary science)	Demonstrations and virtual reality experiments	Quizzes and models
BHS10 (male)	5 years	Misconceptions	Visual arts: drawing	Drawing (secondary technology)	Project-based learning	Projects
BHS11 (female)	1 year	Misconceptions	Visual arts: drawing and models	DNA (secondary science)	Model building and drawing	Models
BHS12 (female)	3 years	Misconceptions	Visual arts: models	Respiratory system (secondary science)	Project-based learning	Models

Findings of the Study

The inductive content analysis following the directed content analysis of the data yielded four themes, which were used to present the findings of the study. The four themes are, (1) perceptions of learning problems solved by STEAM integration, (2) science and technology teachers' perceptions of the arts in STEAM, (3) science and technology teachers' perceptions of STEAM integration strategies, and (4) perceptions of benefits and challenges of STEAM integration in the classrooms.

Perceptions of Learning Problems Solved by STEAM Integration

The science and technology teachers identified two learning problems that could be solved by engaging learners in STEAM activities. These learning problems are discussed below.

Lack of Learner Exposure to Linking Theory Into Practical Work Activities

One of the learning problems identified by the science and technology teachers was that learners are mostly taught in class without engaging in practical work activities. BHS1 shared her experiences, saying:

> *In all my experience of teaching life sciences in rural areas, learners are deprived the practical part of life sciences.*

This was supported by BHS2 who said:

> *The learning problem is that they [learners] grasp the theoretical understanding of matter, but fail to grasp it in a practical, real-life way.*

In the teaching of the technology subject, BHS10 indicated that learners lacked the practical skills of drawing, saying:

> *Learners are having a drawing problem in the subject of technology.*

Therefore, one of the learning problems stemming from the science and technology teachers' experiences was that learners fail to apply the theoretical concepts taught in practical work activities.

Poor Conceptual Understanding Displayed by Learners in the Science and Technology Classrooms

The science and technology teachers identified poor conceptual understanding by the learners as one of the learning problems they experienced in their classrooms. Science and technology teacher, BHS3 indicated that through her experience when teaching the topic of Earth and Beyond, she noticed that learners held some misconceptions. She said:

> *There is a common misconception about the motion of the sun, as some learners wrongly believe that the sun orbits the Earth because of the apparent daily motion of the sun across the sky. Therefore, it is difficult for them to comprehend that Earth's rotation is a cause of this seeming motion. In addition, there is a misunderstanding about day and night. Some learners find it difficult to connect the concept of the Earth's rotation with the occurrence of day and night. As a result, they are unaware that one of Earth's sides is in daylight and the other side has darkness at any given moment.*

To show that learners in the science and technology classrooms held misconceptions, BHS4 said:

> *What I have observed, is that Grade 10 learners cannot correctly visualise the basic structure of an atom. This has led to a poor conceptualisation of the subatomic particles—protons, neutrons, and electrons. Even though most learners can differentiate between the charges of these particles they, however, struggle with explaining the location of the electron orbitals, and where the protons and neutrons are located.*

The existence of this misconception was supported by BHS6 who explained that the STEAM activities he designed help learners improve their understanding of the atomic structure. He indicated that the activities were for:

> *Helping learners to understand the movement of sub-atomic particles when teaching the topic of static electricity.*

In support of the perception that learners held misconceptions in the science and technology classrooms, BHS5 indicated how the misconceptions are evidenced when teaching the topic of Gaseous Exchange. He said:

> *Learners understand the concept of breathing in and out. But the problem is that: (1) they don't understand that as you inhale, the volume of your lungs increases; (2) mastering the concepts such as inspiration and expiration.*

The existence of misconceptions in the topic of Gaseous Exchange was supported by BHS12 who pointed out:

> *They also cannot differentiate the role of different organs involved in gaseous exchange.*

From the participating science and technology teachers' experiences, two learning problems that could be solved by means of STEAM integration strategies were identified, and these were: learners failing to see the link between the theoretical concepts with the associated practical skills, and the lack of conceptual understanding in the different topics.

Science and Technology Teachers' Perceptions of the Arts in STEAM

The participating science and technology teachers perceived the arts in STEAM to be the (1) integration of visual arts in the classrooms, and the (2) integration of dance and music.

Integrating Visual Arts in Science and Technology Classrooms

The science and technology teachers suggested that the visual arts could be integrated in these three ways: (1) use of visual arts drawn and painted on charts, posters, and learners' books, (2) use of visual arts in the form of models and craft, and (3) use of digital technology-enabled visual arts.

Use of Visuals Drawn on Charts, Posters, and Learners' Books.

The science and technology teachers perceived the arts in STEAM as the integration of visual arts as follows. BHS1 suggested the engaging of learners in practical work while learning the topic of phototropism that included the development of visual arts materials. She said:

> *I designed activities that are fun and engaging as learners get to explore STEAM materials in completing all the activities. An experiment which will be done by learners in groups for them to practically see how phototropism occurs and how plants respond to light. This will enhance collaboration, communication, critical thinking, and problem-solving skills. Lastly, learners will be required to make a poster, collage, paintings, infographic, or draw a sketch to show their understanding of the concept.*

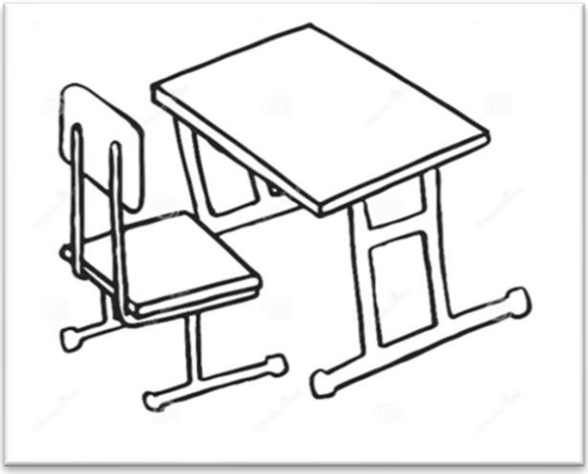
The use of visual arts was supported by BHS5 who had learners draw charts showing the respiratory system. He said:

> *Learners will draw a colourful chart of the human respiratory system.*

In further support of the use of visual arts, BHS6 suggested the drawing of charts and showing of videos demonstrating the movement of electrons in the teaching of static electricity.

In the teaching of technology subjects, learners use drawing to design objects that can be used in real-life situations, and they are required to be creative. In the example given by BHS10, learners can be tasked to design their own versions of desks and chairs that are stable enough to be used in the classrooms. The teacher would give the learners an example of a drawing of a desk and chair in Figure 3 to get them started in creating something different.

Figure 3
Drawing of a Desk and Chair Design Provided by BHS10



Use of Visual Arts in the Form of Models and Crafts.
Under the topic of the Earth's rotation around the sun, BHS3 suggested that learners build models of the earth in relation to the sun. She said:

> *The learners will design and create artistic representations of their own Earth and sun. DIY craft that will develop their understanding.*

Similarly, BH5 suggested the building of human respiratory models when teaching the respiratory system. He said:

> *Learners will create a model of the human respiratory system.*

He provided a picture of the model he created (Figure 4).

Figure 4
Model of the Respiratory System Created by BHS5

BHS12 also suggested the building of models when teaching the respiratory system. She said:

> *As I will be incorporating science, technology, and art in teaching and learning of gaseous exchange, learners will watch different videos based on exchange of gaseous in humans . . . . Learners will also be instructed to design a model of human breathing system. In this case, by designing the model they will be able to understand different organs involved.*

Similarly, BHS8 suggested that learners could build models of electrical gadgets in technology classrooms when they are learning about electrical circuits. He suggested:

> *Implement project-based learning activities in which learners are challenged to design, develop, and present their own electrical circuit projects. This method fosters creativity and problem-solving abilities. For example, learners could be assigned the task of creating a basic electronic gadget, such as a flashlight, and building the circuit needed to make it operate.*

BHS11 suggested the use of both drawing and model building when teaching about DNA. She said:

> *Learners had to design and create a 3-D model of the DNA double helix. The learners first had to draw their designs, then they had to build the model using assorted candy. They were free to use any theme and kind of candy, provided the model was accurate and reflective of the DNA double helix.*

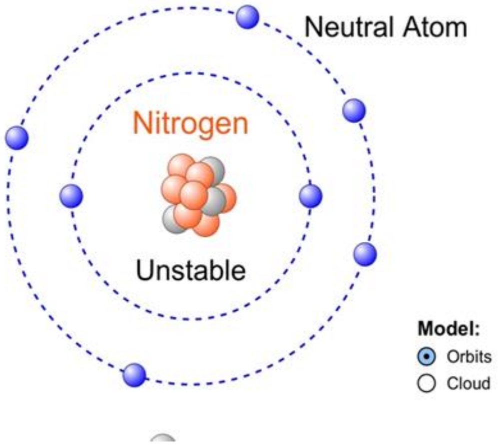
Drawing, making posters, and building models were some of the suggested arts integration methods.

The Use of Digital Technology-Enabled Visual Arts.

Some of the participating science and technology teachers perceived the integration of the arts in the classrooms to involve the use of digital technologies to demonstrate or draw the visuals. BHS4 suggested the use of interactive virtual laboratories for the learners to draw structures of the different atoms when teaching the structure of matter. He said:

Learners will draw their own unique atoms using the PhET simulations. The learner may draw a stable or unstable atom with any colour and reflect on the outcome. Learners can draw and visualise different drawings of atoms [see, for example, Figure 5].

Figure 5
A PhET Application Simulation of an Atom Drawing Provided by BHS4

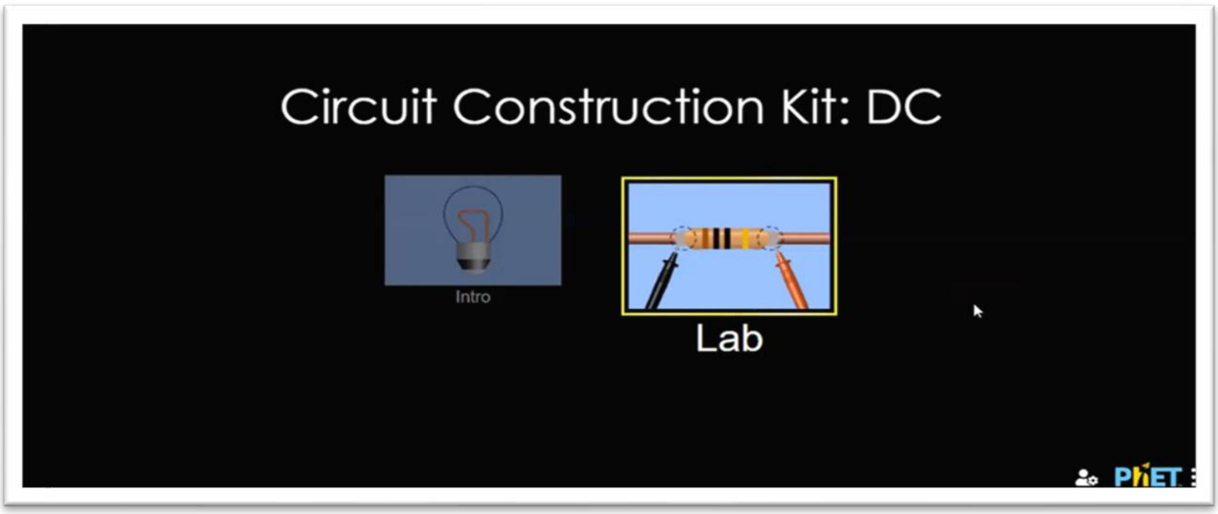


In addition to electrical gadget model building, BHS8 suggested that models could be built using interactive simulations. He said:

Create engaging interactive simulations that let learners investigate electrical circuits in a secure online setting. Learners should be able to interact with various circuit components, such as resistors, switches, and wires, to see how they affect the flow of electricity, through the inclusion of visual and hands-on features in these simulations.

Figure 6 shows the example provided by BHS8 of digital tools used to build circuit diagrams by learners.

Figure 6
PhET Circuit Construction Kit Provided by BHS8



The suggested digital technology-enabled visual arts included the use of videos to demonstrate some concepts in the teaching of science and technology. BHS3 included the use of videos that would provide explanations and demonstrations of the earth's rotation around the sun. She said:

> *The teacher will incorporate a video in the lesson that will provide learners with an explanation of the Earth's rotation and its effect on us (day and night).*

Similarly, BHS6 indicated that the use of charts could be combined with video simulations to demonstrate the movement of electrons. He suggested:

> *Use of visuals such as drawings on the charts brought by the teacher and the use of videos that demonstrate the movement of electrons.*

With digital technologies, the arts integration was done through the use of simulations to draw the structure of matter and build models of electrical circuits. Video simulations were also used to demonstrate the scientific phenomena.

Integrating Dance and Music in Science and Technology Classrooms

Dance and music were also identified as one of the ways to integrate the arts in science and technology classrooms. BHS2, teaching natural sciences and technology in primary school, suggested the use of dance by groups of learners to demonstrate the movement of particles in the different states of matter—solids, liquids, and gases. She said:

> *When exploring states of matter—solids, liquids, and gases—using their [learners] bodies to make real-life models of states of matter gave them the opportunity to be creative in a group format and come up with their own unique movements and models. During this lesson, learners got to have fun with movement and dance while constructing links between theory and real-life examples of states of matter.*

In the teaching of life sciences in secondary school, BHS5 suggested that music could be used in the teaching of gaseous exchange. He said:

> *Learners will work in groups or individually to compose a song based on the different organs of the respiratory system.*

However, examples of such songs were not given.

Science and Technology Teachers' Perceptions of STEAM Integration Strategies

The participating science and technology teachers identified the following teaching strategies that they would use in the implementation of STEAM in the classrooms.

Experiments Conducted by Learners in Groups

Experiments were some of the hands-on activities recommended by the science and technology teachers to use for STEAM integration. BHS1 included an experiment conducted by learners to observe the process of phototropism. She said:

> *An experiment, which will be done by learners in groups for them to practically see how phototropism occurs and how plants respond to light.*

Similarly, BHS2 used experiments for learners to learn about the states of matter. She said she would:

> *Guide students in conducting experiments to observe the changes in states of matter as materials are heated or cooled with a video and practical experiment in class. Instruct students to record their observations and discuss the changes they observe.*

The experiments were also suggested by BHS6 to teach the topic of electricity. He said:

> *Learners work in groups to conduct hands-on activities using materials that include balloons, a darkened room, fluorescent lamps, a sink and running water including computer simulations to demonstrate the phenomenon of static electricity and the movement of electrons.*

Project-Based Learning

Some of the participating science and technology suggested that the STEAM activities could be implemented by engaging the learners in project-based learning. BH8 suggested that learners could be engaged in a project to build an electrical gadget. He said:

> *Implement project-based learning activities in which learners are challenged to design, develop, and present their own electrical circuit projects. This method fosters creativity and problem-solving abilities. For example, learners could be assigned the task of creating a basic electronic gadget, such as a flashlight, and building the circuit needed to make it operate.*

Similarly, BHS9 suggested the use of project-based learning because it enables interdisciplinary learning. He said:

> *The activity will make use of project-based learning that is driven by interdisciplinary learning approach in which the disciplines of science, arts, and technology are incorporated in the session.*

Teacher and Video Demonstrations

Although the participating science and technology teachers perceived STEAM activities to be learner-centred, based on hands-on activities such as experiments and project-based learning, they felt that demonstrations by the teacher or videos were important to guide the learners. This strategy was suggested by BHS3:

> *Learners will watch as the teacher demonstrates the Earth rotation's rotation with the occurrence of day and night using globe and flashlight as well as the YouTube videos.*

The use of teacher demonstrations and videos was supported by BHS4 who said:

> *PhET simulations are used in the teacher-led demonstration to guide learners. The teacher will first demonstrate using the simplest atoms, for example, hydrogen.*

BHS6 also felt that visual media such as charts and videos could be used for demonstrations, saying:

> *[The] use of visuals such as drawings on the charts brought by the teacher, and the use of videos that demonstrate the movement of electrons.*

BHS8 indicated that demonstrations are important when the teachers are introducing new concepts through direct instruction. He said:

> *Introduction to electrical circuits. Direct instruction involves an organised and teacher-centred approach to teaching the fundamental principles of electrical circuits to learners. It usually includes clear explanation, demonstration, step-by-step guidance, and practice and feedback.*

The suggested instructional strategies to implement STEAM included experiments, group work, projects, teacher demonstrations, and videos.

Perceptions of Benefits and Challenges of STEAM Integration in the Classrooms

Through the open-ended reflections, the participating science and technology teachers, expressed their perceptions of the benefits and challenges of implementing STEAM activities in the classrooms.

Perceived Benefits of STEAM Activities

Three perceived benefits of implementing STEAM activities in the classrooms were identified by the participants.

STEAM Activities Are Fun and Engaging for the Learners.

One of the perceived benefits of STEAM activities identified was that they are fun and are enjoyed by the learners. BHS11 explained how she developed STEAM activities in which learners used candy to model the DNA helix, saying:

> *I chose DNA as my topic; this is a complex subject and incorporating the art element helped in making it less challenging and more fun.*

At the end of the activity, the learners could eat the candy they used to build the model of the DNA. BHS11 further said:

> *Another creative twist in the assignment, the model as it is made of candy is edible, learners could then savour their hard work after it was graded! These were the creative tools I used to incorporate STEAM in the activity.*

BHS2 also thought that using dance as a form of art to use in STEAM activities made the activities fun and enjoyable.

STEAM Activities May Address Learning Problems.

With the guidance of the ADDIE model for curriculum design, all the participating teachers had to identify a learning problem to be solved by means of STEAM activities. BHS4, who used the PhET application for learners to draw the structure of atoms, explained how the STEAM activities were used for solving learning problems. He said:

> *Having noticed and analysed the difficulty with visualisation of atoms among physical sciences learners, the infusion of computer simulation as a way to design atom structures takes advantage of technological inclination of the learners as well as the need to visualise PhET simulations.*

BHS8 who taught technology affirmed the notion that learners struggle with conceptual understanding. He said:

> *Grade 7 learners encounter challenges when it comes to grasping the foundational concepts of electrical circuits, which are integral components of their education in the fields of science and technology.*

After using STEAM activities in which learners used virtual reality simulations to draw visual representation of the flow of electrons in circuits and build models of circuits, the learners were expected to improve their understanding. BH8 further said:

> *By the end of this lesson, the Grade 7 learners will grasp the fundamentals of electrical circuits, including components and how they can build a simple circuit.*

The participants were thus able to identify learning problems that could be solved by engaging learners in STEAM activities.

Teachers Become Innovative, Creative, and Problem-Solvers.

Second, the participating science and technology teachers thought that the STEAM activities enabled both the learners and the teachers to develop skills such as problem solving and creativity. In showing that the teachers also needed to apply skills such as creativity and problem solving BHS7, showed how he had to think out of the box when designing the STEAM activities by incorporating digital technologies. He said:

> *I applied innovative, problem-solving, and creativity skills through the development of the "STEAM solution" to address the learning problem. We incorporated an interactive Orrery model, an augmented reality (AR) moon and Earth app, and a lunar phase art installation to enhance student engagement and comprehension. These solutions required creative design, technological integration, and a problem-solving approach to improve students' understanding of celestial motion.*

BH8 agreed with BHS7 that, as teachers, they had to demonstrate creativity and innovation in developing the STEAM activities. He said:

> *In designing the STEAM/STEM activity, I had to think beyond traditional teaching methods and find creative ways to engage learners. This involved brainstorming ideas, considering various approaches, and identifying the most effective way to integrate STEAM elements into the lesson.*

The science and technology teachers also thought the STEAM activities developed the learners' creativity. BHS10 who had five years of teaching experience said:

> *It has opened my eyes to see that already all these years I was not only teaching learners about technology. However, they have been creative in using art in all the processes.*

The design and development of the STEAM activities required the participants to be creative and innovative.

Perceived Challenges of STEAM Activities

The study participants identified three challenges they experienced when developing STEAM lessons, and these are described below.

STEAM Activities Difficult to Align With Assessment Demands.

The participants perceived the development of assessments aligned with the STEAM objectives to be a complex task. BHS7 said:

> *Ensuring that the assessment aligned with the STEAM objectives and accurately evaluated students' creativity and problem-solving skills was a complex task.*

Analysing what BHS10 said about his experience of developing an assessment for STEAM assessment task, it seemed it was difficult for him. BHS10 said:

> *I had to eventually try to develop an assessment task that accommodates STEAM in it.*

This was in addition to learning how to develop STEAM activities. BHS11 indicated how difficult it was for her to assess creativity because, to her, being creative was subjective. She said:

> *Another challenge I faced was how to go about developing an assessment tool for the task learners had to do in response to the identified learning problem. The rubric had to factor in creativity, and this was difficult as creativity is subjective and illogical. What is creative to one person, may not necessarily be the case for the other.*

Developing tasks that assessed STEAM objectives such as creativity, problem solving, and innovation was considered challenging.

Some of the STEAM Activities Are Material Resource Intensive.

The participating BEd honour students indicated that the implementation of STEAM in the classrooms involves the use of adequate learning resources. Some of these resources were not easy to secure. BHS1 said the following about resources:

> *We are only focusing on the theory part due to the lack of resources. Covering all the aspects, the theory, practical, and art in one lesson must be made possible.*

BHS6 shared his experiences with lack of resources in the rural areas, saying:

> *I am still new in the teaching field. However, I have had some experience teaching in the rural area. Because of lack of resources, I still use the old teaching method which is a chalk board for maths. However, for life sciences I have an advantage of a projector, which makes it easy for my learners to view this practically.*

BHS7 also indicated how it was difficult to secure the technologies used to teach the topic earth and beyond:

> *Resource limitations: Sourcing materials and technology for the interactive Orrery model and AR app was challenging. These challenges highlighted the need for effective planning and collaboration to successfully implement STEAM education.*

The findings in this section indicate that STEAM activities are made possible when the required resources are available—and sometimes, this is not the case in some schools.

Teachers' Limited Knowledge of STEAM.

The development of STEAM activities was not without knowledge challenges considering that before this learning experience, the participants had lacked familiarity with the curriculum innovation. BH7 mentioned two challenges that he encountered pertaining to the teacher knowledge required when designing STEAM activities. He mentioned technological knowledge and knowledge to integrate the STEAM disciplines is critical, saying:

> *Technological proficiency: Developing the AR moon and Earth app required learning new software and tools. Integration Barriers: Ensuring seamless integration of science, technology, engineering, arts, and mathematics elements in the project was complex but essential.*

In agreement with BHS7, participant BHS8 also mentioned how the ability to integrate the different disciplines in the STEAM activities could be a challenge:

> *One of the primary challenges was finding the right balance between the various components of STEAM, ensuring that each element was meaningfully integrated.*

The other challenge indicated by the participants in terms of teacher knowledge pertained to curriculum design method used in this study for the STEAM activities. BHS6 said the following about the ADDIE method:

> *For me it was a little bit challenging to understand how ADDIE works and how to incorporate it into a lesson plan. I had to watch YouTube videos to get better understanding.*

Technological knowledge, STEAM design knowledge, and knowledge to integrate the STEAM disciplines were identified as limited by the participants.

Discussion

This study focused on the how participating science and technology teachers used design principles to develop STEAM learning activities for classroom practice. Using Papert's constructionism as a lens, the study made the assumption that, in order for the participating teachers to be able to implement STEAM in the science and technology classrooms, they needed to engage in the design of curriculum materials (Henriksen, 2017; Keane & Keane, 2016). The need for the teachers to engage in design and developing of curriculum materials led to the deliberate decision to prescribe the ADDIE model of instructional design to guide participants as they engaged in STEAM design activities (Budoya et al., 2019; Hess & Greer, 2016). Anisimova et al. (2020) argued for the training of the STEAM teachers in design.

Four major themes led to four major findings of this study. First, by engaging in design, the teachers were involved in problem solving and thereby identified some learning problems that could be solved by engaging learners in STEAM activities. The analysis stage of the ADDIE model results in the identification of the problems to be solved by the design and development of the curriculum materials (Budoya et al., 2019; Hess & Greer, 2016). These learning problems included the alienation of theory from practical work experienced by learners, and misconceptions displayed by learners about different topics. In order for the participating teachers to solve the identified problems, they designed solutions based on STEAM activities.

Second, the participating teachers had to be creative and innovative to design and integrate the arts component of STEAM for science and technology classroom practice. Forms of visual arts, dance, and music were designed and incorporated in their STEAM lesson plans. Perignat and Katz-Buonincontro (2019) confirmed that there are various interpretations of the arts, and that outcomes for integration also vary. The visual arts were integrated as (1) drawings and paintings on charts, posters, and learners' books, (2) models and craft created by learners, and (3) digital technology-enabled visual arts. The digital technologies included virtual reality, augmented reality, and videos.

The third finding revealed the instructional strategies perceived by the participating science and technology to be suitable for the implementation of STEAM. The instructional strategies included experiments conducted by learners in groups, project-based learning, and demonstrations led by the teacher or viewed from videos. Hawari and Noor (2020) and Temiz and Çevik (2023) also used project-based learning in their studies of the implementation of STEAM in the classrooms. STEAM activities enable learners to create artistic products, and allows them to engage in design thinking and problem- and project-based learning as strategies (Ozkan & Umdu Topsakal, 2021).

The fourth finding revealed the participants' perceptions of the benefits and challenges of engaging learners in STEAM activities. The participants identified three benefits, which were that (1) STEAM activities were fun and engaging for learners, (2) STEAM activities addressed learning problems and (3) STEAM activities pushed teachers to be creative and innovative in curriculum development. STEAM education is lauded for its potential to develop innovation and creative skills in learners. Similarly, teachers have been observed to apply open-mindedness and innovation when implementing STEAM in the classrooms (Jho & Song, 2016). The observation that STEAM activities are fun and engaging may explain why, in the study by Baidal-Bustamante et al. (2023), learners in the experimental group completed the activities faster than the learners in the control group.

The participants also identified three challenges, which were that (1) STEAM activities were difficult to align with assessment demands, (2) STEAM activities are material resource intensive, and (3) teachers displayed limited knowledge when implementing STEAM in the classrooms. Hawari and Noor (2020) affirmed that STEAM activities exert curriculum demands that teachers need to overcome. In addition, learners need materials to create the STEAM products they design, and these materials may not be available in some schools (Temiz & Çevik, 2023).

Conclusion

In conclusion, the theory of constructionism enabled the BEd honour's degree students to learn by designing and developing STEAM curriculum materials (Ackermann, 2001; Kynigos, 2015). The ADDIE model of instructional design guided the students to develop STEAM activities and instructional strategies that helped them find solutions for learning problems identified in the science and technology classrooms. As the students engaged in design thinking, they were able to apply innovation and creativity skills. Visual arts in the forms of drawing, painting, virtual reality and augmented reality, and the building of models were used in the STEAM activities. Music and dance were also employed to create ways of expressing scientific phenomena. STEAM activities allowed both the teachers and the learners to engage in design thinking. Accordingly, the study makes a recommendation to include design thinking in the professional development of STEAM teachers.

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