STUDENTS' PERCEPTIONS OF A STEM-BASED CURRICULUM: A PHENOMENOGRAPHIC APPROACH

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ABSTRACT

Students can perceive STEM in a number of ways that can affect what they gain from STEM curricula. This qualitative study characterises secondary school students' perspectives of integrated STEM lessons using the theoretical framework of phenomenography, to see how they interpret and conceptualise STEM for now and the future. Thirteen participants were engaged in guided conversations that revealed their perspectives of integrated STEM lessons that they had earlier engaged in. Ten qualitatively different ways in which students perceived STEM were uncovered and a possible outcome space for developing STEM curricula was derived. Participants perceived that they had developed deeper intellectual abilities, collaborative skills, understanding of assigned projects, and professional identities. The findings of this work are intended to inform a design of STEM curriculum that will improve STEM learning and outcomes in a holistic manner. Implications and suggestions for the design and integration of STEM based on the results of this work are also presented. *[African Journal of Chemical Education—AJCE 13(3), July 2023]*

INTRODUCTION

Science in conjunction with mathematics, engineering and technology play a concerted role in the sustainable development of any industrialized society through motivation which is embedded in a constructivist approach [1]. It is predicted that 47% of today's jobs will require technological development [2], possibly from the study of science, technology, engineering and mathematics (STEM). However, figures from literature indicate that only few people are in the field [3], regardless the demand for workforce in STEM related occupations [4]. Countries that wish to progress technologically, therefore, have to take interest in STEM studies to ensure that their citizens fit into future technological and STEM-related jobs appropriately.

These anticipated STEM-related jobs have led to a demand in a holistic integration between Science, Technology, Engineering and Mathematics [5, 4] to help students make interdisciplinary connections between concepts [6]. In this wise, STEM must be considered a crucial element towards sustainable development [1, 7]. Experts agree that the knowledge of STEM, when integrated, could be applied to solve problems and sustain the world [7]. STEM lessons begin with real-world (indigenous) issues that offer opportunities to learners to experience real-world contexts in interdisciplinary ways, with the belief that tomorrow's occupations are found in it.

The objectives of STEM integration are solid knowledgebase among students and enhancing of their interest in science, technology and mathematics, as well as strengthening their abilities to integrate and apply knowledge and skills gained. Integrated STEM encourages 'systems thinking' about sustainability [8]. It seeks to nurture students' creativity, collaboration, and problem-solving skills [3]. In other words, it attempts to increase learners' STEM literacy towards knowledge gain and understand scientific and mathematical concepts and processes required for personal decision making and participation in civic and cultural affairs for economic productivity. This leads to increased awareness of societal needs and improvements, cognition, and positive beliefs of students as observed by York, et al. [9] in their study of systems thinking in STEM education.

STEM requires that students engage in hands-on real time projects that give them opportunities to take risks with mistakes, so that they can appreciate its underlying concept [10] and view science literacy as a composite system. This implies that students must understand the nature of their environment so that they can be fit to live in and be lived with, as each contributes their own quota positively towards technological development and sustainability. This could also expose them to STEM-related careers that are needed for now and the future. Students' achievements in inventive science and pathways that create STEM-literate graduates could create generate innovators, making STEM different from traditional instruction [11, 12].

BACKGROUND

STEM instruction in Ghana is monodisciplinary rather than interdisciplinary, where students are taught STEM as individual subjects. This could make it difficult for students to see connections between science disciplines and to appreciate the entirety of science studies and its connection to other non-science disciplines. According to York and Orgill [13], skills associated with the interdisciplinary approach or integrative 'systems thinking' are part of science literacy so that the development of learning skills can prepare students to understand and address complex real-world problems.

In order to attempt a reversal of the current lag in STEM efforts, and to begin the integration, deliberate efforts were made to integrate STEM in lessons in selected deprived Ghanaian high schools, with rich culture and communal support in an interdisciplinary approach [10]. This was to make participants impact their local communities positively in their everyday activities and appreciate the principles of STEM. It was to further raise the awareness of STEM among students and their community through real-world problems in teams. Information about STEM models and related stories were told with enthusiasm and passion to stimulate a liking for STEM-based careers, after which context-based projects that involved community members were assigned to students. Constructivist-based teaching and learning approaches were adopted so that students could develop their own valid knowledge and perceptions about STEM and desired content knowledge. Attributes such as carefulness, honesty, patience, analytical deductions, predictive skills, time management skills, critical thinking, deductive and reflective skills necessary for the development of STEM disciplines were embedded into the community-based STEM projects. An example of such a project was the study of polluted water beneath a bridge from biological, chemical and social perspectives, after which the design of a durable bridge with appropriate metals over the water (river) to save aquatic life was required in miniature form.

The integrated STEM programme in a previous study was designed partly to inculcate the desire for STEM careers at an early age, improve innovation and ensure social equity to boost up female representation as suggested by Sias, Nadelson, Juth and Seifert [5]. The females, especially, were observed to be prepared to learn from risks, which traditional learning spaces mitigate. Pre-project interviews and observations were carried out to assess students' perceptions of STEM caused by the integrated real-world nature of STEM projects. These findings have been reported in another paper [10].

The framework for the STEM integration (prior to the current research) assumed a phenomenological approach, where STEM domains, bound by STEM practices within authentic contexts for the purpose of connecting subjects to enhance student learning were included [14]. The phenomenological approach studies the diverse ways in which people perceive phenomena and present findings as perceived within a particular study. Its integration framework included six tenets, which were to motivate students for STEM subjects, use constructivist student-centred pedagogies, apply engineering designs, include teamwork and communication, and adopt developmental learning [1]. The tenets of constructivism, prominent to active learner participation in problem-solving of real-life contexts was employed as students interacted with the environment, such that knowledge, as a function of cognition, could be used to organize their experiential world [15].

This current study assessed a mix of all three major research paths that are commonly undertaken in STEM studies as well as York, et al.'s [9] systems thinking approach. Based on reviewed studies, the researcher attempted to ascertain students who had engaged in integrated STEM's perceptions about their engagement [10] in and out of regular classroom sessions. The current study further attempted to find out unexplored perceptions, as well as define an outcome space, with respect to the concept of STEM.

PERCEPTION

The concept of perception is the sensory experience of the world that involves recognizing environmental stimulus and actions in response to it through perceptual processes that enable one to gain information about the properties and elements of the environment that are critical for survival [16]. It is a process in which people are aware of objects and events in their external worlds as they go through five events of stimulation, organization, interpretation, evaluation and memory, and recall [16]. Perception is described as the awareness, comprehension or understanding of 'something', and must be marked by the exhibition of three major elements: motivational state, emotional state and experience, with the first two elements contributing largely to how a person perceives a situation [17]. In other words, people determine their attitudes and preferences by interpreting the meaning of their own (self) behavior. Some other times, observation of the attitudes of others could affect an individual with a sense of merged identity [18, 17].

The principles that guide the perception theory are that perception is relative and not absolute. It is selective and has arrangement that may differ from one person to another, although the environmental conditions could be the same [17].

The self-perception theory posits that people determine their attitudes and preferences by interpreting the meaning of their behavior. Perception is, therefore, the realization of human brain processes that manifest as a view about phenomena. Feelings, needs, motivation, experiences, and many more of affective expressions are involved [19].

Perception starts from the five basic senses and the brain's ability to accept a relayed information in a sequential manner. Perception, therefore, becomes the realization of processes of one's brain about a phenomenon, followed by a reaction to the object and concluded by an arrival of meaningful interpretation of a stimulus [20]. This is a complex process that is physical, physiological, and psychological.

Empirical studies on students' perspectives of integrated STEM activities

There have been several studies in recent years about awareness creation and the engagement of students in STEM activities towards the development of STEM attitudes and skills for lifelong learning and STEM careers [21, 22, 23, 9]. Baran et al. (2016) studied the perceptions of 18 females who were engaged in out-of-school STEM activities and how these influenced their STEM skills cognitively. Roberts et al. (2018) similarly elucidated perceptions of STEM learning after engaging learners in an informal summer STEM activity and found out how these impacted on their in-school STEM skills. Participants in the different studies expressed diverse ideas with descriptions of discipline personalities that could influence their abilities to take on STEM role identities. Verdin, Godwin and Ross [23] went beyond students' perceptions on cognition to find out the ontological beliefs of students with specific attention to the ways in which they described characteristics of STEM personalities and how these influenced their own abilities to take on those role identities. York et al. [9] also studied STEM in a more holistic manner by employing the idea of systems thinking in STEM education.

It was observed from literature that participants commonly perceived STEM as fun, enlightening, availing an enabling environment for hands-on activities, and supporting classroom learning. A significant implication is to identify the expansiveness or otherwise of other perceptions, which were not found in reviewed literature, and incorporate them into the design of STEM curricula to further uncover unexplored areas of STEM.

THEORETICAL FRAMEWORK: PHENOMENOGRAPHY

The theory that informed the study stemmed from theories on perception that was directed by the phenomenological approach. Here, perception is the sensory experience of the world that involves recognising stimulus and actions [16]. This has consequences in the current study as perception principles imply that though students may be exposed to a common learning concept under one environment setting, their views could differ, based on their physiological and psychological inclinations and what they deem selectively important [24, 18]. One other factor to perception could be the perceiver's own past experiences that could bear on their current perception [25].

Justification for adopting a phenomenographic approach

The current study focused on assessment of individual perceptions of an integrated STEM phenomenon through phenomenography. Phenomenography is a qualitative research methodology, within the interpretivist paradigm, that investigates different ways in which people experience or think of something [26]. Its ontological assumptions are subjectivism but as it has the character of knowledge, the ontological assumptions are also epistemological assumptions [27]. The different ways in which students experience, interpret, understand, perceive and conceptualize the STEM phenomenon or aspect of reality was defined [28]. Here, sample and experience were considered as a whole and experiences based on the relationship between a person and the world around them. Thus, how participants conceptualized STEM is regarded truthful by the researcher [29]. In phenomenography, it is assumed that there are no wrongs or rights in the phenomenon under investigation, as the researcher is not interested in what is truly ‘real’ but in how a person conceptualizes a phenomenon under study.

Phenomenography differs from phenomenology in that phenomenographers adopt an empirical orientation and investigate the experiences of others. Phenomenology focuses on the essence of a phenomenon, whereas phenomenography focuses on the essence of the experiences and the subsequent perceptions of the phenomenon. Once data is collected in phenomenography, it is organized and reviewed to identify the number of ways that a phenomenon has been experienced or conceptualized. The three main principles for the identification process are:

i. Categories should be extracted from participants' responses;

ii. Categories should not be mutually exclusive or inclusive, but distinguishable;

iii. Responses must be explicit for categorization.

'Categories' describe the qualitatively distinct perceptions which emerge from collected data in phenomenographic studies. These categories of descriptions are the main outcomes of the research, and these are often presented in increasing levels of understanding. Phenomenography, unlike other qualitative studies, is different in its major premise, assumption, and principles of categorization [30].

This phenomenographic framework was suited for the current research as the main interest (objective) was in students' qualitative perspectives about the integrated STEM approach in an outcome space and contribute new findings to literature.

An Outcome Space

A phenomenographic framework allows for the definition of an outcome space that describes how students' perspectives are related and fit into an experience as a whole [31]. Outcome spaces can be developed in different ways. Some could be hierarchical in nature or assume developmental progression [32]. Each category of description often has a focus that is examined and arranged on the expansiveness or otherwise of other perspectives. This current study took a look into students' STEM perspectives, to subtly find out perceptions about integrated STEM in relation to the environment and possibly, sustainability.

RESEARCH QUESTION AND SIGNIFICANCE

This study examined students' perspectives of a STEM project using a framework of phenomenography. In view of the desired goals, the overarching research question was:

- What are the different ways in which students perceive the concept of STEM in integrated-STEM lessons and projects?

The primary goal of the study is to contribute obtained data on integrated STEM to educators and curriculum designers to build STEM lessons and projects that meet the goals of STEM for national STEM plans. It is also to promote student learning of content, address students' lack of interest in STEM and poor enrolment through a friendly curriculum and help them to gain the necessary STEM skills for lifelong living and national development.

METHODOLOGY

A phenomenographic qualitative approach [26] that employs purposeful sampling was used to drive the defined objective and answer the research question. The phenomenological lens used in this study enabled the researcher to understand how students perceived integrated STEM through their broad description of experiences and subsequently assessed them phenomenographically. The object of phenomenographic study is not the phenomenon per se, but the relationship between the actors and phenomenon [33].

A purposeful homogenous sample of 13 students aged between 15 and 17 years, which was a little over 10% [34] of the sample in the preliminary study, was voluntarily chosen to provide the needed data on their perceptions of integrated STEM lessons. The sample necessarily had to consist of those who had experienced integrated STEM and indicated a predisposition for STEM lessons for one school term in an earlier phenomenological study (Author, 2020a) and could provide information-rich data. Borrows, Nowak and Mooring [29] followed a similar protocol to assess students' perceptions of a laboratory environment.

After permission was obtained from the institution's headteacher, students were briefed about the intended study. The sample read and signed consent forms before the researcher engaged in a guided conversation with them. The guided, focus group conversation involved six boys and seven girls and was conducted using a semi-structured protocol which lasted between 8 and 22 minutes with an average time of 15 minutes per item. Follow-up questions were used to clarify students' responses to initial questions when necessary. Participants' responses in the course of their projects and during the focus group conversation (interview) were not prompted or suggested in any way by the researcher. Conversations lasted until data saturation [35] was reached and no new perspectives were uncovered. Pseudonyms were employed in the descriptions.

Some of the conversation questions are shown as Appendix A.

To establish the trustworthiness of results, two rounds of debriefing were used to establish the consistency, dependability, and credibility of the coding system. Two colleagues with experience in qualitative research but no experience regarding this integrated STEM study served as analytic audience. Transcripts were read and coded using NVivo 12 for MAC. The codes were revisited, revised, and elaborated after several comparisons. Codes were collapsed to organize the data into themes and further analyzed to ensure reliability. Further analysis was carried out to develop semantic themes, which attempt to identify obvious meanings in statements, theorise the significance of the patterns- their broader meanings and implications [36, 29] and compare obtained data with that of the past to draw inferences. The students' perspectives were considered to be important products of phenomenographic research because they described the diverse ways that they perceived integrated STEM lessons.

The analysis was expected to be a compilation of a series of categories and descriptions which was fitted into an outcome space to reflect the increasing complexity of perspectives, with the view that the adopted method would tease out students' perceptions about STEM for use by curriculum developers.

RESULTS

From the guided conversation, it was clear that students had fair perceptions of what STEM was, as they had worked through STEM projects for one school term. Some of their perceptive responses were:

- *'STEM is doing science or Math in a new way by connecting them more.'*

- *‘It is integrating Math into practical science.’*
- *‘It is practical science and technology.’*

The responses suggest that STEM is ‘hands-on’-based, allows for practice and skill development and is multidisciplinary. STEM is also seen as real-life or real-world practice of science theory, in the comment:

- ‘STEM means merging all sciences and *taking it to the community* to *solve problems* practically’.

In this response, STEM is again perceived as multidisciplinary. It is perceived to go beyond mere school practice, to *solve* ‘real-world’ problems. Students in this category could be said to perceive STEM from a *problem-solving* perspective.

When asked about their future careers, a response was:

- *‘To be a STEM teacher and not just a Math or science teacher ‘.*

This interesting answer was probed further and the response was:

- *‘You see, the STEM does it all and students see science, math and tech work together in unison. It is good to combine the subjects like that for understanding… you apply them to solve given problems faster as each subject bears on the other’.*

This response that said that '*STEM does it all'*, could be interpreted to mean that students view STEM as an all-encompassing discipline (multidisciplinary), and could be problem-solving inherent.

Other career-oriented responses were:

- *'To be an architect as I love math and design activities'*
- *'To be an engineer because I like the physics and math part of projects'*
- *'Pharmacist; I will learn about human beings and how to administer hospital or traditional medicine properly to heal the sick: not a doctor, really'.*
- *'I found out about many STEM careers than I could think of but have not settled on any.'*

Other STEM careers like dentist, actuary, software developer, physician assistant, civil engineer, cartographer and many others came up.

Students further expressed their views about their experiences in the STEM projects, some of the inventive things that they came up with, some challenges, and how these influenced their decisions to pursue some of the STEM-related careers that they had expressed interest in.

Ama said that it was *fun, interesting and engaging*. Hetty said that it led to *peer discussions and teaching, which was very helpful*.

Hetty and Ama appeared to perceive STEM from social and collaborative viewpoints.

James said: '*Remember that I designed scientific and time-saving machine for the coconut and palm oil producers close to the market? Hetty in my group did a similar thing for the fish smokers*'.

According to Tricia, '*group members James and Grace helped to identify resilient types of metals and clay for efficiency after several trials and suggested them to the potters and metal works craftsmen. We can be managers or consultants or something of the kind for small-scale businesses. Yes? (Colleagues nod in agreement). We also share the main things that we have to do and everybody does internet research for ideas and solutions for our project'*.

The mention of 'several trials, consultancy, and internet research, could be interpreted to imply the perception that STEM is viewed as *exploratory, research-inherent and provides high-profile career orientation*. Again, the use of *skills* and *content knowledge* are inherent in STEM, as submitted by Tricia. Furthermore, Tricia's group perceive STEM from a *research perspective* as problems have to be analyzed. *Skills* and *content knowledge* have to be perused and solutions deduced from the possible trial of ideas.

To the question on how the STEM project *impacted on their learning*, all the students except one, unanimously responded positively. Some said that it made them *learn harder* as they often needed to *apply theories* in their out-of-class projects without textbooks. Others said that *realization* dawned on them that *everything that they learned in school mattered for understanding*, for example, 'how things like machines and the world 'ticked''.

The researcher, content mastery and application of knowledge, as well as problem-solving perspectives were implied in these unanimous answers. The perceived multidisciplinary nature of STEM became more obvious in responses to how STEM impacted on their learning, than when the question was asked on what STEM was. Students also perceived that content knowledge was an important variable in the multidisciplinary STEM approach, as reiterated by Eric.

Eric said: almost *all science subjects work together as one,* in order to achieve good results.

Eric's response was probed further. Responses that came up answered the question on students' views about the integrated STEM approach. Students perceived that to be able to solve real problems successfully, one needed to acquaint themselves with *content knowledge* from *all the STEM disciplines and apply* 'bits' of each to *deal with problems* successfully and so STEM disciplines should not be taught in 'isolation' like independent islands. Again, almost all the students in this study perceived that the project *contributed to their learning in class and vice versa*.

Ama disagreed with the positive attributes of integrated STEM from her colleagues. She was quite vocal on her answer about the difficulty in implementation of the projects.

Ama: *Mmm, I am not sure…. In the beginning it was not easy. Too many things to remember and apply. It was difficult. The outdoor was good, but the project…. not fun. Later, I did learn though (shrugs).*

Though Ama's response appears to be negative, in effect she perceives that STEM is *all-encompassing (multidisciplinary)* and requires *mastery of STEM principles* for one to be successful.

She nonetheless reiterated the fun and social part of the project. She enjoyed going out of class with colleagues, nonetheless.

An overview of the entire STEM projects and students' candid perceptions were gathered and analyzed into categories as stated earlier. Most of the students' views have been paraphrased with highlights on important perceptive phrases. Most of these perspectives focused on the *unexplored aspects of science* within the communities. Students reiterated that they were *prepared for challenges* that could arise with projects because they could *solve problems in innovative and exciting ways*. They perceived that STEM was more of *'real science'*. They reported that projects made them feel like *real scientists*. They recapped the fact that they were happy to *expand their school science knowledge* and *apply it to the unknown for a better world*.

It is obvious from the phrases italicized that the students saw STEM from the explorer, innovative, mastery of content, skills acquisition, application of knowledge, and problem-solving perspectives. Some of their perceptions were:

- 'I think the STEM work is cool. I loved to *apply my ideas from class to new situations*. In fact, in this new type of lesson, you *feel free to do things*..., I mean *try them out* without restrictions, but safely.'
- 'I felt very much at home when we visited the pharmaceutical industry. I said to myself that, 'ah, *that's the job for me''*.

- 'I think I have already *gained so many skills* for the future, Ma'am …. just one term of STEM. I can hardly wait for more of such all-inclusive lessons this new term'.

STEM is being perceived as *career-oriented*, *skills-developing*, and *exploratory* in these responses.

Generally, almost all participants reported that the integrated STEM was *effective*, *interesting*, and *engaging* (hands-on and collaborative) which enhanced their *acquisition of innovative and STEM skills.* They perceived that the real-time experiences allowed for prediction, observation, hypothesising, conceptualisation, communication, manipulation, computation, elucidation of patterns, reflection, assertiveness, and articulacy in science language as observed in an earlier study [37].

Outcomes from the guided conversation sessions further showed that students had some degree of positive perceptions about the flexible constructivist STEM environment. These participant-statements and many more which have not been presented allowed for the categorization and definition of an outcome space that describes how the obtained perspectives relate and fit into a whole experience.

SUMMARY OF OBTAINED DATA

Ten distinct perspectives were uncovered as students' perceptions about STEM (Table 1) interpretively. The columns are filled with the researcher's categorizations and interpretations and not exact student phrases.

Table 1: Students' perspectives and focus on STEM

Student perspectives	Students' focus
Multidisciplinary perspective	Acknowledging usefulness of STEM's interdisciplinary nature
Researcher perspective	Applying acquired skills to gather data, interpret, analyse, find patterns, and arrive at conclusions
Content mastery perspective	Building and deepening content knowledge
Skill developer perspective	Developing and practising STEM skills for lifelong learning
Career-oriented perspective	Understanding importance and application of STEM skills for future careers & economic independence
Collaboration perspective	Interacting on a higher level to augment purposeful learning
Real-life practice perspective	Applying 'school science' to 'out-of-school' or 'real-world' situations through hands-on and minds-on activities
Problem-solving perspective	Developing innovative and pragmatic approaches to identified challenges and new situations
Socialisation perspective	Social interaction for fun
Explorer perspective	Exploring the unknown in STEM

It is important to note that the study participants do not belong to only one categorized description since they expressed their views among several of the categorizations. The descriptions of the ten categories that exemplify the identified perspectives in Table 1 are discussed more clearly below.

Analysis of perspectives for construction of outcome space

Multidisciplinary perspective

Students identified the interconnectedness of the STEM by responding to the nature of STEM as being encompassed by '*all disciplines in one bag'*.

- *'You see, the STEM does it all and students see how science and math work together in unison. It is perfect to combine the subjects like that for understanding… you apply all to solve same or given problem constructively'.*
- *Adzo: The STEM combines all the different sciences, technical drawing and math and so it is like a one-stop or one-shot subject …. or teaching that employs everything... Here you learn everything in one lesson, even though the lessons are longer. But Ma'am it is better than attending a standalone Physics class (chuckles). Math is a challenge but my colleagues in my group helped out.*

These perspectives describe the important integrated nature of STEM which must be embodied into the design of STEM programs. The students' perspectives are in line with how More et al. [1] also describe integrated STEM. It further affirms what York et al. [9] also found in their studies on systems thinking in STEM education.

Researcher perspective

Students with such researcher perspectives focused on using the STEM environment to explore their learning environment through scientific methods. They shared tasks, gathered necessary information, and analyzed them for best options and practices methodically. This is supported with the response: *We do online research to get more ideas and solutions*.

This portion from Tricia's response suggests the researcher perspective description: *I loved to play the science investigator and problem-solver, all in one…*

Then there was Adzo*: The hands-on activities or the project, I should say, make you engage with work at a deep-thinking level. It's like you have to reflect really deep, but before all that, the real work is searching for helpful information.*

Carrying out research involves a scientific process. Interpretively, this equips researchers with data collection skills, analysis of information from different sources, critical thinking, planning, report writing and a complement and extension of classroom learning. This is a notable aspect of STEM to be included in its design as it will not only create independent and critical thinking persons, but also independent problem-solvers as identified from literature studies [3].

Content mastery perspective

The integrated STEM environment was seen as favorable for deepening of concepts and skills that appeared far-fetched and abstract to students.

- *Tricia: The activities were intricate and cut across many subjects that we know……like math hands-on activities, chemistry practical activities, biology activities…..and engineering. We actually needed all many concepts from different subjects to complete our project.*
- *Eric: I loved the 'out of class' science in the community and relatives saw us as real scientists. Parents think it is prestigious to read science so I loved that my community saw me. It made me learn harder to understand better and will strive hard to be a great engineer to build modern roads and bridges … with some new materials that will come up.*

The perception, that knowledge gained from lectures could be used to solve problems in the 'real-world', is important as it spurs students on to learn intensely to apply content knowledge to real life problems practically (Author, 2020a). This is summarized in '*We actually needed to always learn different concepts from different subjects to complete projects.*

Students who expressed this 'content mastery' perspective were interested in applying previously acquired knowledge to solve problems and to deepen their overall learning experience. This implies that the design of STEM projects should scaffold content and their applications. A similar observation was made by Wang, Moore, Roehrig and Park [7].

Skill developer perspective

Some respondents perceived that the integrated STEM provided access to hands-on activities and set a stage for them to meet professionals in STEM who they wished to model as well as learn on-the-job skills. They were happy that the skills learned through the STEM projects could have practical significance and application for the future. A student with such a perspective develops understanding and finds joy in the application of developed skills. They look forward to engaging in ‘real’ activities that involve the practice of mathematics and physics, they alluded. Students perceived that they built their self-confidence, cognition, and prepared themselves for their future career paths through STEM. Pursuance of the development of such skills and perceptions among students would help to close the existing gap in STEM skills and careers and fit the projections made by Frey and Osborne [2]

- *Roy: We engaged in more real activities than ever before in areas like math and physics where we hardly did activities. Sometimes we improvised some of our materials which worked like what we find in books. I built my confidence level with using the scientific instruments.*
- *James noted, “I love to build things like planes, trains, some toys for play, but I never knew that I had to do a bit of chemistry….like, knowing about the types of useful materials and ….properties and the best ones for efficiency. See, with the Ship project, we revised properties of alloys in our group, weighed, measured…put the manufactured toy in water and discussed density, then the real field activity was great. I felt like a proper scientist”*

- *Grace added, "I loved it best when an industrialist, vets and lady pharmacist came to help us to learn procedures (skills) to prepare tablets and suspension medication for ailments. I can even prepare drugs if I can get the raw materials because now I know how".*
- *Tutu: I can handle the micro equipment and take measures better than before. I enjoyed using it at home and during in-field activities.*

Career-oriented perspective

Eric had expressed, in addition to how peer engagement benefitted him, that integrated STEM lessons and work in the community made him want to be an engineer to build roads and bridges. Other participants had similar ideas about moving into STEM careers.

- *Tutu: This project exposed me to different kinds of work (careers) that we could purse. The pharmaceutical lab would be my career. It was fun to be allowed to spend a day at the pharmaceutical industry. I was excited, yet apprehensive. When the realization set in that I could also be like them…woow….*
- *Effuah: I see a lot of chemistry, technology, engineering and how to keep our environment in the petrol industry. I loved to combine chemistry and environmental science in our projects so I would like to pursue a career like that as I want to be like the females. I will choose a university course for that.*

- *Hetty: You see the science in many things that our parents do at home like the 'banku' (corn meal), beads, pottery, and pito (fermented cereal drink), if the science and technology in the process is explained such local businesses can expand to empower the women financially.*
- *Ama: That is very true. The indigenous women practise more science unknowingly, until we explained to them how they could improve and expand their business in more scientific ways.*
- *Yaw: Most of the local industrialist looked…mmmm. poor or something, but with our knowledge we can teach them to do their profit and loss, whether they are gaining or not, and then teach them to improve on their style of production and sales. I think if we engage in such trades more scientifically and technologically, we could improve local industries……I think..*

The 'career-oriented' perceived STEM through the lens of career training. Understanding of concepts, mastery of concepts and skills and their application were developed based on how they could be applied to future careers.

Collaboration and higher-order thinking perspective

Higher order thinking perspectives were perceived a illustrated with Hilda and Manu.

- *Hilda: I got excited with ideas during STEM lessons. The activities were thought-provoking. Working alone would have been difficult for me. My Math is bad …. eish! We contemplated expansive ideas outside the box for common success.*

- *Manu: Yes, my team members and I supported each other with our knowledge in different areas, even if the grouping was changed. The group work helped us to understand the main connections in projects in bigger ways.*

Practice-oriented perspective

Engaging students in hands-on activities or constant practice leads to the acquisition of desired skills and retention of knowledge.

- *Ama: Ms. Attu's math always led to something concrete like using the knowledge to prepare aspirin, gather materials to make a particular extent of a wall, model something concrete. That prepares me for the world of a surveyor, engineer, pharmacist, agric engineer …. Even when we had to make farm beds, it was measurement. Math is in every career.*
- *Hilda: Activities were involving because you apply things from mathematics and science theories and solve real community problems, but it makes you understand and remember.*

Hilda's perspective could easily be captured as a problem-solving perspective; an indication that some students expressed more than one categorized perception of STEM. The 'practice-oriented' participants perceived STEM through practical hands-on activities of some learned theories. They perceived that mastery of knowledge and skills come through practice. They further perceived that developed conceptual understanding, from practice, could be applied usefully in future careers.

Problem-solving perspective

Some students found the integrated STEM projects as fun and yet challenging- a ground for solving what they commonly referred to as 'real science' problems.

- *Tricia: The exposure to real life problems and how we solve them helps to connect all the dots in what we learn. I loved to play the science investigator and problem-solver, all in one (Chuckles). There is always some real practical activity to do to solve a given problem. The hands-on activities were engaging. You figured out solutions like in a puzzle to solve problems.*
- *James buttressed the problem-solving perspective with: You feel an air of success when you solve scientific tasks in the community or classroom successfully. It's a good feeling. Like, you understand how science, math and engineering designs and technology, give expected solutions. Every task is a challenge that must be solved in a scientific manner, Prof.*
- *Hetty: The STEM has made me wiser, smarter, with techniques to solve community and our house problems. Like using bicarbonate, lemon and charcoal to sanitise and clean things. I look impressive when I put my STEM ideas to work.*
- *Tutu: I think of the assignments (projects) given and assemble in my mind, knowledge I need from everywhere. I reflect and then decide the specific scientific principles to combine for solving the group's problems. All the other members have to do same.*

These students are focused on the application and extension of gained skills and knowledge to solve 'real' problems. The problem-solving nature of STEM is epitomized in their responses. They relied on and applied acquired knowledge to solve problems.

Socialization perspective

Collaboration is a desirable characteristic but must be 'useful' and geared towards a desired and intended goal and not merely for socialization and fun. It is true that collaboration can ensure knowledge creation [3], but must stem from within, in an academic environment, to steer one onto to the creation and acquisition of knowledge.

- *Hetty: I loved the 'out-of-class' projects.*
- *Yaw: Even Doreen and Mansa (not interviewed) engaged actively in the STEM projects. It's fun working collaboratively.*

The concept of STEM, as presented by Hetty and Yaw, does not truly spell out the implied STEM objectives.

The perception of STEM being for fun or socialization is limited. To 'love' the project and be 'active' towards no goal achievement is a limited perspective. 'Social perspective' students perceived STEM projects as environments for pursuing social interactions. A similar observation was made by Burrows, Nowak and Mooring [29] when they carried out a similar study. They, however, placed their socialization perspective at a higher level as they felt motivated by the 'fun' side of STEM lessons and projects.

Explorer perspective

Students with the 'explorer' perspective described opportunities that were inherent in the STEM for finding out more about their environment and identifying links between the school and 'real-world' environments for growth and development. They emphasized on how acquired knowledge and skills could be applied in both situations, as shown in the excerpt:

- *Tricia: Working with community members was interesting …. learning about their local science and we explaining our school science in their real work. I think we can learn harder and truly help the traditional local science potters, kenkey makers and bead people…. and the blacksmith and other people who use some kind of science.*

The explorer perspective could be an advantage as various routes to achieving an ultimate could be explored for best, innovative, and inventive solutions. This also increases students' initiative and decision-making skills. This is summarised in: '*In fact, in these new lessons, you feel free to do things...,try activities without restrictions*'.

DISCUSSION OF THE OUTCOME SPACE

An outcome space that describes how students' perspectives are related and connect into the STEM experience as a whole is characteristic of phenomenography [38]. In this study, the primary emphasis of each category of description was examined and arranged in levels based on how inadequate or extensive the perspective of STEM is. Levels were constructed on the basis of reviewed literature that could provide reasonable grounding for designing, analyzing, and suggesting optimal activities for the integration of STEM through a multidisciplinary approach in real classrooms.

Perspectives on higher levels have broader views of STEM, while those on lower levels are limited in coverage. Furthermore, each of the derived perspectives was compared to the objectives of STEM (integrated) as outlined in this manuscript to arrive at the classification of levels. The objectives of STEM include developing solid knowledgebase, enhancing interest in STEM, strengthening abilities to integrate and apply the knowledge and skills gained, and nurturing students' creativity, collaboration and problem-solving skills. An outcome space, based upon a summary of identified levels is shown in Figure 1.

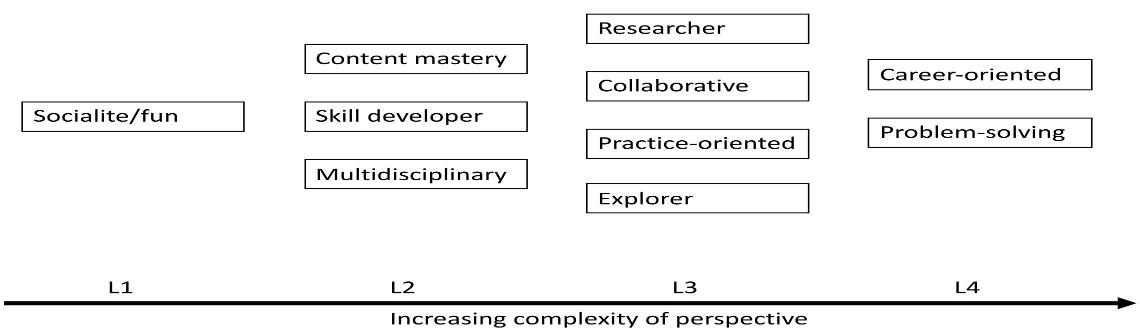

Figure 1: Outcome space describing increasing complexity of students' perspective of STEM

From Figure 1, the socialization perspective in Level 1 represents the lowest level of perceptions because this was the least frequently mentioned perspective among the categorizations. The focus of students' expressions in this group does not portray commitment to explore the integration of STEM or achieve its objective but have 'fun'. There is, however, a fair amount of interest in the fun side of project activities and so cannot be ruled out completely as trivial.

The multidisciplinary, content mastery and skill developer perspectives were viewed as more complex than the socialization perspective in Level 1. This is because students focused on notable goals of STEM; that is, to master content and develop the necessary skills for STEM. However, they lacked the entirety of the STEM objectives. There is no emphasis or mention of the use of gained skills in an interconnected manner nor their application to real world issues. There is no suggestion on how these skills could be augmented through collaboration.

The third level perspectives are deemed more sophisticated in outlook. These are the 'researcher, collaborative, practice-oriented, and explorer' perspectives. These perspectives are on a higher level because they seem to be more aligned with the objectives of STEM. Students with these foci perceived that STEM increased their opportunities to apply acquired skills and transfer knowledge in new situations, interact with others to share useful ideas on a higher level to solve real problems, and explore other ways of attaining better outcomes for identified challenges than have fun [10, 3]. Here, the perspectives included integration and application of knowledge and other gained skills, for lifelong learning.

In Level 4, the 'career-oriented and problem-solving perspectives' were chosen as the highest level of the outcome space because they are more encompassing, spelling out the implied ultimate aim of STEM and beyond. These perspectives suggest that mastering and applying gained skills in collaborative and explorative ways could lead to interventive and innovative approaches to solve real-world problems; this would ultimately lead STEM students to STEM-related careers for sustainable, environmental, technological and economic growth. The awareness of STEM-based careers which could lead to technologically sustainable societies was implied as connections between theory and practice. Concepts, skills and problem-solving attitudes were expressed. This is epitomized in Hetty's problem-solving perception: *The STEM has made me wiser, smarter, and equipped me to solve community/house problems. We will get good work in future.*

In summary, Hetty's statement covers the tenets of the second major STEM objective, which is for personal informed decision making and participation in civic and cultural affairs for economic productivity. It also underpins another charter of STEM- to equip students with skills to be employable in STEM-related jobs for the future [4].

Findings from the analyzed guided conversations suggest that the flexible learning space provided by the STEM project proved to be an interesting experience and impacted positively on students. They alluded that the high percentage of hands-on activities included in their STEM curricula was the reason for their success in assigned projects. Students perceived that the engagement made them think at a higher intellectual level and demonstrated that contextualizing teaching could afford improved quality of learning. Many of the students admitted to positive changes in cognitive, affective, social, perseverance, self-respect, respect for others, collaborative, and process skills.

It must be emphasized that most students were found to be sitting across a range of different perspectives and not confined to any one particular perspective.

The creation of a STEM community by inviting role models, sending students out into the community to solve real-life problems, engaging with people in indigenous industries and discussing the underlying science principles in their work helped to bridge the gap among industrial, indigenous and school science. In this study, most of the community projects involved indigenous science, where men and women, especially, were observed at using traditional/indigenous science to make local foods, beads, pottery, blacksmithing (production of alloys) and alcohol. The decision to engage with more women in small-scale business was to partly encourage females on the STEM project. These women explained the science in their indigenous crafts and spurred the students on to learn harder to develop contemporary ways of improving their arts scientifically. These real-life meaningful contexts were seen by students as important to themselves and the nation. They had the opportunity to improve on their tolerance and collaborative skills through activities.

It could be inferred from students' guided conversations that they began to develop diverse professional identities where they suggested that they were not merely students learning about scientific theories but people who could analyze situations and propose workable solutions to them, as Roy said.:

- ‘*The projects gave us … at least me …. more insight in how real work or profession in our course area is like. It is all about the different parts of science into one composite unit in the real adult working world; and developing solutions to the assigned challenges was great. It gives me so much confidence now with regards to learning science from all angles and using it to work confidently in future’*.

It is clear that integrated STEM education could educate students about the role and importance of STEM for sustainable development in order to manage socio-scientific issues related to the application of science-related technologies innovatively. The seeming increase in the positive appreciation of STEM could be due to a sense of merged identity as suggested by Goldstein and Cialdini [20] and by holistic teaching as intimated by York, et al. [9].

CONCLUSION

This study provided an overview of what students perceived integrated STEM education could look like in practice in the contemporary science classrooms [39, 40, 41]. This study provided students in an underrepresented environment access to variety of practices in STEM fields and contact with professionals at their workplace through visits and hands-on projects. Outcomes of their

STEM projects gave them the propensity to want to change societal and natural orientations and to be less reliant on teachers.

Reviewed research articles suggest that STEM education has the potential to help students to learn more meaningfully through an integrated approach and prepare them for future careers, ethical actions, and sustainability [42]. The incorporation of the degree of importance (from the levels of categorisation) of what students perceived to gain from STEM curricula was not identified from previous literature. It was perceived from the guided conversation that students developed and demonstrated almost all of the known researched objectives of STEM and a few more new ones.

Ten main student perceptions about STEM were uncovered, though some students possessed more than one major perspective [11]. These perspectives related to career orientations, application of scientific concepts, innovation, cognition, affection, and skill-based components of STEM. Designing STEM curriculum with such student perspectives could move students into higher or engaging levels of STEM through meaningful experiences. Students perceived that out-of-class activities connect them to 'real science', technology and mathematics, and allow them to explore various design routes, or at least give them suggestive ideas.

The STEM also deepened their understanding of concepts that had a theoretical significance for them. From the arranged categories of descriptions of perceptions (in Figure 1) where perspectives were on the fun side of the out-of-class, STEM skills and understanding of theories were gained. Some students identified a practical application of some of the theories that had been learned in class in some of the indigenous science that they engaged in or observed. They described how they could improve on the indigenous science through principles that they acquired from their school science. The implication is that skills obtained through STEM could have practical significance for the future, especially career-wise [4].

The study further highlighted how integrated STEM approach could influence students' perceptions about STEM, based on students' own impressions. The use of problem-based mini projects allowed students to connect to real-world experiences and observed from first-hand how STEM-integrated lessons holistically led to successful designs and construction of an intended outcomes. It helped to awaken their innovative skills also. The skills obtained could have practical, personal and national significance for the future. They also perceived that knowledge gained from real-world situations could be used to solve problems in school and vice versa.

The STEM perspectives uncovered in this study encourage future research on STEM that can employ a longitudinal study of students, especially, for those who display more than one main perspective. It also shows how students' perspectives operate holistically when design elements have to be considered. These observations suggest the near supremacy of interdisciplinary teaching and learning over unidisciplinary teaching and learning as identified by other researchers [39, 5, 21, 1, 7].

All identified perspectives are important for STEM development and must form part of STEM-designed curricula, in general school curricula. It is hoped that the categorization or creation of levels of outcome space in this STEM study would provide guidance (through later development of an exemplar curriculum model) for teachers and curriculum planners about essential goals of multidisciplinary education as perceived for integrated STEM education. Considering the existing findings from literature as well as this current study, that increased workforce in STEM-related careers would be required in the coming years [11, 3, 2], it is important that students who have participated in STEM-integrated projects are engaged to articulate their perceptions to see whether they fit intended objectives and ultimate goals. Findings from data-based categories in this study further suggests the importance of STEM studies and how gathered data could contribute significantly in advancing STEM education research and practice across all levels of education.

IMPLICATIONS

These findings contribute to the existing literature on integrated STEM. Understanding the different student perspectives present in an integrated STEM classroom (noted in this study) could be of use to teachers and STEM educators, because teachers could develop lessons to emphasize how 'classroom' knowledge could be enacted to solve 'real-world' problems in homes and communities. They could also use integrated STEM classrooms to provide context to students about how acquired knowledge could be applied in their future careers. Furthermore, allowing an element of freedom in one's classroom could allow for exploration of answers to higher-order problems through various research routes. This could also equip students with the needed inventive and innovative skills for future careers and national development. Students' perceptions and rating about the interesting and effective or other teaching methods is a way to suggest improvements in the teaching-learning process.

It must, however, be noted that perception is a complex phenomenon that is relative, selective, has its own arrangement and differs from person to person even if the same environmental conditions are provided, due to one's past experiences and their psychological makeup [25]. This knowledge must inform zealous teachers about expectations with innovations on STEM in their classrooms.

LIMITATIONS

The study investigated the perceptions of students engaged in an integrated STEM approach from a single class in an institution. This might not be reflective of all other classes or institutions, though the diversity of participants lends to a wide scope. Not all the 103 participants who enrolled on the project in the beginning in the session engaged in the guided group conversation. Their views could have been different from that captured in this study. Nonetheless, data saturation was reached for the 13 participants who engaged in the guided conversation. Their performance based on the new approach was assessed in an earlier study and so was not addressed in the current study. Besides, there was lack of pre-measurement of the STEM projects that participants engaged in, as this was a baseline or initial study of such a kind in the study area.

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Appendix A

a. What does STEM mean to you?
b. What would you like to be when you grow up?
c. Can you tell me about your experiences and values gained in projects that you undertook?
d. What were some of your difficult and fascinating experiences?
e. Describe some inventive things that happened during the project and how they bear on your future career.
f. How did the project activities contribute to your learning?
g. Did the projects relate concepts in class/lab to things in the home or community and vice versa?
h. What are your views about this method of teaching science with different disciplines integrated into a unit?
i. How has the integrated STEM approach affected your perceptions about science, science careers and STEM in general? Kindly give an overview.