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Research Article

# Assessing the Effectiveness of Science, Technology, Engineering, and mathematics (STEM) Education on Students' Achievement in Secondary Schools

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**Abstract**: The education community has become aware of the need to change the way STEM courses are taught because of the good effects STEM programmes have on students' academic performance, attitudes, and interests as well as their communication and problem-solving abilities. STEM education is supposed to increase students' conceptual understanding of how science and mathematics are interrelated so they can better understand engineering and technology. One of the long-term objectives of every educational institution is to raise students' academic achievement. With the quasi-experimental research control design utilised, the study aims to examine the contribution of STEM education in secondary schools. Consequently, it utilises a multidisciplinary strategy for integrating STEM - to the field of STEM education, and discusses STEM literacy; factors influencing students' engagement in STEM education; effective pedagogical practices, and their influence on student learning and achievement in STEM; and the role of the teacher in STEM education. Three essential components were found after a thorough analysis of the studies: (1) the importance of focusing on the secondary phase of schooling to maintain student interest and motivation to engage in STEM, (2) the implementation of effective pedagogical practices to increase student interest and motivation, develop 21st century competencies, and improve student achievement, and (3) the development of high-quality teachers to positively affect students' attitudes and motivation towards STEM.

**Keywords:** STEM; STEM integration; conceptual understanding; students' achievements, STEM education

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## 1. Introduction

The changes in science, technology, and economy radically transformed countries' points of views towards education. The term "STEM education" is an approach that integrates science, technology, engineering, mathematics and has especially brought innovation to science education (Bybee, 2013). It typically includes educational activities across all grade levels, from pre-school to post-doctorate, in both formal and informal settings. STEM is an acronym commonly used to describe education or professional practice in the areas of science, technology, engineering, and mathematics. An authentic STEM education is expected to build students' conceptual knowledge of the interrelated nature of science and mathematics, in order to allow students to develop their understanding of engineering and technology (Hernandez et al., 2014). STEM which is also called interdisciplinary is the creation of discipline based on the integration of another disciplinary knowledge into a new whole (Lantz, 2009). Therefore, STEM education is also evaluated as a bridge between education and career (Gomez & Albrecht, 2014). The integration of disciplines has been discussed in a variety of ways (e.g., design based, problem based, project based, inquiry-science and engineering implementation) in literature in STEM education (Park et al., 2018).

In the 21st century, workforce related to STEM fields has become increasingly important (Wilhelm, 2014). This integration of instruction has changed expectations from individuals, as well. As a result of these expectations, a new trend called STEM education has emerged.

A meaningful learning environment is provided by the inclusion of STEM education in school curriculum. McCaslin (2015) asserts that STEM education is an essential instrument for enhancing students' comprehension and expertise in related subjects. Additionally, constructivism and cognitive ideas are embraced by STEM learning integration (McCaslin, 2015). This idea is said to help students since they learn more when they actively participate in class rather than just listening, concentrating on critical thinking, and developing conceptual grasp of issues. In STEM learning classrooms, students are accustomed to cooperative learning and discussion, learning by questioning and exploring, investigating into various tasks, and applying the knowledge they possess (Olivarez, 2012; Bada & Olusegun, 2015; Shahalin et al., 2017). Classroom environments should be focused on collaboration and exchange of ideas (Bada & Olusegun, 2015). These learning activities can increase students' interest in the STEM fields that eventually produce STEM-literate citizenry (Becker & Park, 2011).

The integration of STEM activities can cultivate student thinking skills which can help students form the ability to analyse, evaluate, make conclusions and arguments correctly and logically about problems to be solved (Chia & Maat, 2018; Dwyer et al, 2014). Tolliver (2016) stated that students need to possess useful innovation and creativity skills in finding solutions to any related problems. STEM integration can create active, creative, critical, and communicative human beings (Bahri et al., 2014; Tolliver, 2016). During STEM activities, students are learning contextually and focusing on the applied knowledge of STEM to solve real-world problems (Berland et al., 2014). Hence, meaningful STEM activities are challenging for educators to develop and integrate for raising students' interest and eventually to boost their academic potential in STEM subjects (Shahali et al., 2015).

Improving students' academic achievement is one of the long-term goals of any educational institution (Brown, 2012). Prior research has shown the integration of STEM has a positive impact on elementary, middle, and high school student achievement (Hansen & Gonzalez, 2014; James, 2014; Judson, 2014; McCaslin, 2015; Tolliver, 2016). For example, McCaslin's (2015) experimental studies with fourth-grade schools in Georgia has shown the effects of STEM education on student achievement on number and operation, data measurement, and analysis, geometry and algebra. The assessment showed that there were improved results in the achievement of students following STEM-based learning. Ashford (2016) discovered that the STEM after-school program increased the academic achievement of 75 third, fourth, and fifth-grade students. Similarly, Olivarez (2012) found that a STEM program had a positive impact on 176 eighth grade students' mathematics, science and reading achievement.

Several studies have reported STEM integration can improve student involvement during classroom instruction. Educators who integrate STEM into the learning process encourage students to be active learners. Meaningful activities should include all the STEM disciplines and the real-world application so that students can see the connection between the content they are learning with their daily life context (Kuenzi, 2008; Osman & Saat, 2014). In fact, Thomas (2013) stated that more coordinated activities in the STEM could cultivate students' positive attitude in encouraging them to pursue further mathematics. Also, H. Wong and R. Wong (2010) claimed meaningful STEM activities do not solely improve the understanding of concepts but increase student interest in these subjects.

The integration of technology and engineering into school education has been proposed as an effective means to enhance student learning and raise student achievement in STEM disciplines (Brophy et al., 2008). Technology and engineering activities have been shown to develop STEM literacy and increase motivation, in addition to providing real world contexts for learning scientific and mathematical concepts (NRC, 2012). Engaging students in activities that are fun, hands-on and linked to everyday contexts improves students' attitudes towards STEM subjects, which may then encourage them to pursue STEM-based careers (Koszalka et al., 2007). Importantly, research indicates that an increasing number of teachers are integrating these types of pedagogical practices in their classrooms, although the scope and level of implementation varies between teachers, schools and countries (Lim et al., 2013; Tondeur et al., 2010).

A growing body of research has examined the influence of technology integration on student achievement, with findings from these studies reporting mixed results. Some early studies reported positive but small to moderate effect sizes (C. Kulik & J. Kulik, 1991), whereas more recent research has yielded mixed findings (Machin et al., 2007), with many studies reporting comparable achievement levels when technology was not implemented (Ehri et al., 2007; Torgesen et al., 2010). Implications from this research highlight an important point – the provision of technological resources to schools is not sufficient – teachers and students require technological competency to engage effectively with these tools. Interestingly, international research examining the influence of one type of mobile technology – laptops - on student learning outcomes has generally shown no significant increase in learning outcomes when 1:1 laptop initiatives were implemented in schools (Silvernail et al., 2011). Thus, further research is needed to inform future strategies for effective mobile technology integration in the classroom. In the area of mathematics, research indicates that children enter the early years of schooling with a range of mathematical abilities (Houssart, 2001). Without exposure to effective pedagogical practices, students exhibiting delays in their knowledge often fall behind the rest of their cohort for the duration of their formal schooling (Morgan et al., 2009). Other studies have confirmed the importance of developing core mathematical competencies in the early years of schooling, as these competencies have been found to predict both current and future mathematics achievement (Duncan & Magnuson, 2011). Thus, the early years of learning, including Kindergarten and the lower primary years, are an important focus for the implementation of pedagogical practices to promote student learning and achievement in mathematics. More positive findings have been reported in the science domain with reform efforts in international science education advocating the implementation of constructivist learning and teaching approaches, that employ authentic, inquiry-based pedagogical practices to make connections between student's existing knowledge and currently accepted scientific knowledge. Research indicates that when students actively engage in authentic science inquiry in collaborative groups, they are afforded opportunities to act like scientists (Bricker & Bell, 2008; NRC, 2012). As a consequence of engagement in meaningful science experiences aligned with authentic science practices, students have been found to display increased motivation and interest in science, and improvements in student achievement (Fang & Wei, 2010; Herrenkohl & Guerra, 1998).

The integration of STEM in school curricula aims to strengthen the ability of students to be critical thinkers and analytical problem-solvers (Nasarudin et al., 2014) through interactive learning experiences. Although STEM positively improved student achievement outcomes, there are still some negative results when integrating STEM activities that are evidenced by James' (2014) study which showed that there were no effects using the STEM approach on the mathematics achievement of seventh graders in central Tennessee. This failure might have occurred due to the teacher being less trained in the STEM approach or the lack of school support. Additionally, the study participants were not on the same mathematics level as indicated by the findings. Along the same lines, when applying a specific STEM approach in the classroom, the role of the teacher is essential (McCaslin, 2015). As teachers have a significant role in student learning, they must understand the content, prior knowledge, challenge and support for students to learn actively in building new understanding and being able to solve various mathematical problems.

Although the STEM education approach has become popular recently, the attempts to implement STEM education have been increasing both in national and international platforms. It is considered that the explanation of the implementation process of the integrated STEM education which aims to develop the 21st century skills of the new raising generation is important for the individuals' career options (Bybee, 2013). The investigation of contributions of STEM education to students' critical thinking skills and career awareness will also set a good example for teachers and researchers to perform STEM education implementations. Some researchers in the field assert that it is important to increase students' awareness of learning the disciplines, but teachers who carry out STEM implementations have difficulties with their administration (Nathan et. al., 2013).

Empirical data on STEM education in primary through high school was utilised in earlier research (Hansen & Gonzalez, 2014; James, 2014; Judson, 2014; McCaslin, 2015; Tolliver, 2016). In order to raise student success in STEM disciplines, all of these research included STEM activities into the teaching and learning process. The findings of this study are expected to address the need for the implemented educational activities as stated in the pertinent literature and to contribute to the integration of engineering, technology, and mathematics disciplines into science education (NRC, 2012). Additionally, it is anticipated that the study will help students become more multidisciplinary conscious of the value of engineering discipline integration in scientific education for the creation of real-life settings. The study's findings are particularly significant because they can push teachers to actualize STEM education implementations while also helping students build their critical thinking abilities and attitudes towards STEM fields in light of design-based learning.

The research aims at determining the effectiveness of STEM education on students' achievement in secondary schools. In line with this purpose, the study sought to test the following null hypothesis:

1. There is no significant difference in students' achievement when taught with STEM education and when taught conventionally.
2. There is no significant difference in students' critical thinking abilities when taught with STEM education and when taught conventionally.

## 2. Materials and Methods

The research design used for this study was the quasi-experimental with a pretest-posttest control group design. The population in this study was the SHS (1) students of Tamale Senior High School. The sample consisted of two classes selected by cluster random sampling. General Arts Class 1H, as the experimental class, was given a treatment of STEM learning approach and General Arts Class 1B, as the control class, was given a treatment of conventional learning. Data collection techniques used were tested to get data on students' achievement and their critical thinking skills.

Multivariate Analysis of Variance (MANOVA) was used at the hypothetical testing stage. The data on students' achievement and their critical thinking abilities was obtained after the samples were given treatment. Statistical tests were performed at a significance level of 5% using the SPSS program. Before the data is used for hypothesis testing, the data must meet the prerequisite tests of the Multivariate Analysis of Variance (MANOVA). MANOVA requires that the data must be normally distributed and homogeneous.

## 3. Results and Discussion

The data obtained from the test and questionnaires regarding the use of the STEM learning approach and conventional learning. The average score in the study can be seen in table 1.

**Table 1.** Data Distribution of the Research Result

| Statistics | Students' achievement | | Critical thinking abilities | |
|---|---|---|---|---|
| | Experimental | Control | Experimental | Control |
| Mean | 84 | 75 | 72 | 68 |
| Median | 80.00 | 67.34 | 84.44 | 66.67 |
| Standard deviation | 6.736 | 10.252 | 7.133 | 9.060 |
| Variance | 45.374 | 105.104 | 50.880 | 82.084 |
| Max score | 89.00 | 80.67 | 95.56 | 75.56 |
| Min score | 67.00 | 45.00 | 62.78 | 57.78 |

Table 1 shows that the average score of students' achievement using STEM is higher than the average scores of students' achievement using conventional learning. Similarly, the average score of students' critical thinking abilities using the STEM approach is higher than the average score of student learning outcomes using conventional learning. Before testing the hypothesis, the prerequisite tests were performed which include the normality of data distribution and the homogeneity of variance. The prerequisite tests have fulfilled the requirements for hypothesis testing.

To test the first hypothesis, the Between-subjects Effects Test was used and results are shown in table 2.

**Table 2.** The Result of Between-Subjects Effects Tests

| Source | Dependent variable | Sig. |
|---|---|---|
| Class | Achievement | .000 |
| | Critical thinking abilities | .003 |

It can be seen in table 2 that the achievement of students who were taught using the STEM learning approach produces significance less than 0.05. This means that the H0 is rejected and the H1 is accepted. It proves that there is a significant difference in achievement between students taught with the STEM learning approach and conventional learning. To test the second hypothesis, the Between-subjects Effects test was also used. The results of the analysis are presented in Table 2. It can be seen that the significance of students' critical thinking abilities taught using the STEM learning approach is less than 0.05. This means that H0 is rejected. The hypothesis H1 indicates a significant difference in students' critical thinking abilities taught using the STEM learning approach compared to conventional learning. To test the third hypothesis, the Multivariate test was used. The results of the analysis are presented in Table 3.

**Table 3.** The Summary of Multivariate Test Results

| Effect | | Sig. |
|---|---|---|
| | Pillai's Trace | 0.001 |
| | Wilks Lambda | 0.000 |
| | Hotelling's Trace | 0.000 |
| | Roy's Largest Root | 0.000 |

Table 3 summarizes the Multivariate test results. It is known that the values of the Pillai's Trace, Wilks' lambda, Hotelling's Trace, and Roy's Largest Root are smaller than 0.05. Based on the results of the MANOVA test analysis, it can be concluded that there are significant differences in students' achievement and their critical thinking abilities when STEM education is used.

STEM education is said to be effective if after using this approach, there is an increase in students' achievement and their critical thinking abilities. To know the effectiveness of the STEM learning approach, the effect size formula was used. Effect size indicates the extent to which a variable affects other variables in a study. The results of the analysis are presented in table 4.

**Table 4.** Results of the Effect Size Analysis

| Class | Average gain | Standard deviation | Effect size | Description |
|---|---|---|---|---|
| Experimental | 0.56 | 8.694 | > 0.8 | High |
| Control | 0.23 | 10.712 | | |

After obtaining the effect size from the data, then the step next was to compare the value of the effect size with the table to find out how much STEM learning approach influenced students' achievement and their critical thinking abilities. The STEM learning approach was implemented in the experimental class and conventional learning was implemented in the control class. It can be seen that the average value of the experimental class was higher than the control class. The distribution of the mean values of pretest and posttest of the experimental class and the control class are respectively shown in Table 2 and Table 4.

## 4. Conclusions

The effectiveness of science, technology, engineering, and mathematics (STEM) education in secondary schools were explored in this study. Since incorporating STEM into curricula has been suggested as a successful way to improve students' learning and academic performance across disciplines, the goal of STEM education is to help students become more analytical problem solvers and critical thinkers.

It is clear that students' performance in senior high school is impacted by STEM instruction. We may infer that the increase in student achievements between STEM and traditional learning can be measured by comparing the data outputs.

Based on these findings it is recommended that the STEM approach of instruction should be employed in all secondary schools in the country. This will lead to production of the critical labour of people with analytical problem-solving skills and critical thinkers. More so, the country needs such a critical labour force for its development.

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