Role of Engagement in Predicting 6th - Grade Students' Performance in an Integrated STEM Life Sciences Unit

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Abstract

In this research to practice paper, we have focused on the role of engagement in predicting students' performance in an integrated life sciences unit.

Prior literature has shown that students' engagement plays a vital role in developing their interest in STEM (Science, Technology, Education, and Mathematics) courses, their performance, and their selection of college majors and careers. One way of achieving this engagement is by actively engaging students in science courses at an early age. Considering the role of active engagement in science classes as a critical factor to students' performance, we designed an integrated Life STEM curriculum unit, and associated assessment for 6th-grade students. We developed curriculum materials applying the effective strategies for science and engineering integration identified in previous research. We introduced the curriculum unit to 11 teachers in eight middle schools across the Midwest region of the USA. We collected pre and post achievement and engagement data from these teachers' classrooms. Specifically, we collected data from 1100 6th grade students for their pre-engagement (before the implementation of the curriculum unit) and post-engagement (after the implementation of the curriculum unit). Academic performance data were provided for 915 6th grade students. We used the modified multidimensional engagement instrument, "The Math and Science Engagement Scales," for students' engagement data. The instrument has four dimensions, which are behavioral, emotional, cognitive, and social. Students' academic performance data were collected through a content assessment designed by the project team.

In this study, we specifically explored the role of students' pre-engagement in predicting students' performance in the curriculum unit while accounting for students' prior performance. We used multiple regression analysis to explore the relationship between each dimension of students' engagement and performance. We also explored the change in students' engagement from pre to post studying the curriculum unit using multivariate ANOVA. The results indicate that students' pre-assessment, behavioral engagement, and social engagement are the significant predictors of their performance in the post-assessment. Also, results indicate a significant change in all engagement dimensions from pre to post. In this full paper, we discuss these results in light of the integrated STEM approach and previous literature evidence. Further, we discussed the limitations and implications of the study and provided future directions for the research.

Introduction

Students' engagement is one of the primarily focused areas in STEM education to promote positive behaviors and a sense of belonging in students [1]. This focus is specifically crucial in middle and high school students as their engagement can lead to students' interest in STEM disciplines and improve their school experiences [2]. Literature supports that student engagement can raise the achievement levels of students. One way to achieve these higher levels of engagement is with the use of challenging teaching practices that promote deeper learning in students. Further, the consistent use of engaging teaching practices can be useful to narrow the achievement gap [2].

Considering the role of engagement in students' achievement, we explored the role of students' pre-engagement in predicting their achievement in a Life STEM curriculum unit. We created a conceptually designed integrated life sciences and engineering unit by using consistent and challenging teaching practices. We used the Integrated STEM-based approach [3], [4] to

design and teach the curriculum unit around an engineering design task and principles. Based on this curriculum approach, we also explored the changes in students' engagement after compared to before the use of integrated teaching practices.
More specifically, we explored two research questions:

1) To what degree do students' pre-engagement predict their academic performance in the curriculum unit while accounting for students' prior performance?
2) How do students' engagement change with the use of Integrated STEM-based teaching practices and curriculum?

This study is a subset of a more extensive longitudinal study where we are collecting data from multiple middle schools located in the Midwest of the United States. The study presents the findings and results of students' engagement change as a result of the implementation of the curriculum unit and teaching practices at the 6th-grade level. The more extensive study is implemented with students in 6th, 7th, and 8th grades.

Literature Review

Existing research on students' motivation showed a strong relationship between students' engagement and their learning, achievement, and performance [5], [6]. Studies showed that school engagement, as described by behavioral and affective dimensions, plays a significant role in the academic performance of the students [7]–[9]. For example, Finn and Rock [9] found that engaged students showed evidence of regularity in attending classes, participation in classroom activities, and most students performed well. Similarly, Steele [10], in the context of Black Americans, argued that students' engagement is essential in schools for their performance and can contribute more than abundant resources for the classroom environment. He argued that the absence of engagement could lead to underachieving students, even in the presence of ample resources and appropriate focus on knowledge and skills. However, the tricky aspect remains three fold 1) what practices teachers can use to engage students and keep them motivated? [11], [12], 2) how to design grade level and course content appropriate engagement curriculum for students? [13], and 3) how to measure students' engagement as a multidimensional construct [14], [15]?

In recent trends, many studies in the K-12 environment have focused on devising ways that could promote greater engagement and, in turn, could participate in improving students' performance. A commonly used variation was by engaging students in an innovative curriculum or teaching practices. These practices included the use of robotics [16], [17], gamification [18], [19], Integrated STEM education strategies [20], [21], and other active learning activities [22], [23] in the curriculum. However, an important aspect to note is that in middle schools, such teaching practices are often incorporated in science and mathematics courses [24]–[26].

One of the commonly used mechanisms to design grade level and content appropriate engagement is the use of Integrated STEM education in middle school classrooms. Moore et al. [27] defined Integrated STEM education as an effort or way to combine the four disciplines of science, technology, engineering, and mathematics into one class, unit or lesson, where these integrations could be based on subject-based connection, placed in a context, and surround real-world problems. Further, these integrations could be useful in teaching the STEM context to enhance students' learning and engagement [4]. Studies showed that the use of Integrated STEM education in K-12 classrooms helped with students' learning, motivation, and performance [20], [21], [28]. Also, Integrated STEM education provides opportunities for "more relevant, less fragmented, and more stimulating experiences for learners" [28, p.186]. However, similar to most of the practices, even the Integrated STEM education focused on science and mathematics content in K-12 space and lacked literature on the life science curriculum [24].

Considering the lack of literature that introduces a novel, engaging, and challenging teaching practices, the present study addresses the gap and uses the Integrated STEM approach to introduce the subject-specific content. In this paper, we focused on integrating engineering principles into the life science curriculum. Also, this study emphasizes the role of students' engagement in their academic performance and examines whether or not such integration impacts students' engagement.

Curriculum Unit and Professional Development

We designed and introduced the curriculum unit by using the Integrated STEM approach. We used the amalgamation of content and concepts from multiple STEM disciplines simultaneously with an engaging context of the problem. We gave students an ill-structured problem of water pollution. Specifically, in the situation of heavy rain, stormwater discharges directly to the local river without any treatment by the wastewater plant. The curriculum unit and teaching practices considered the current concern of the city, which is the frequent water overflows contributing to the pollution in the river.

We asked the students to design a water filter that could help to prevent the pollution of a local river for the city's wastewater management plant. The problem has multiple potential solutions, and students were to use and apply the knowledge and practices from various knowledge areas of STEM disciplines. As the unit was introduced in the life sciences and engineering curriculum unit, the science lessons addressed the human impact on the river ecosystem and the interdependent relationships within ecosystems.

Throughout the unit, the students learned about and utilized a model of the engineering design process that is included in the curriculum unit. The design process included the stages of exploring or defining the engineering problem, learning necessary science content, planning solutions, building a prototype, testing the prototype, refining the prototype, and sharing information. The unit included the mathematical concept of flow rate in the engineering challenge. After students designed their stage one, mechanical filter, they tested it, which included calculating the flow rate of the design.

To ensure fidelity of implementation across schools, we invited teachers of the school to attend a summer professional development training. The teachers were introduced to the curriculum unit and student-centered, inquiry-based teaching practices, where the teacher could facilitate the students, but let the students be an in-charge of their learning and understanding. The teacher implemented the unit in their classrooms during the subsequent school year.

In addition to professional development training, we observed each teacher multiple times during the implementation of the unit. The researchers' observation notes indicate both the fidelity of implementation and also students' engagement during the unit. Teachers solicit student ideas on topics to be learned and discuss how the topics are related to the project to be completed. The students brainstorm possible solutions, share these ideas with the group, then the group merges the ideas into one possible solution. A key component is to have the students support why they feel the solution works and how it is better than another solution. Having the students analyze the prototype after testing to look for improvements is a crucial feature that cannot be rushed. Students need to be able to articulate weaknesses in their prototype (even if it takes teacher prompting), then propose and test new solutions. Setting up the classroom environment to support collaborative work and encouraging students to share ideas is a crucial factor in the success of these team activities. The teachers encourage student engagement in a variety of ways, including connecting the content to their previous knowledge and offering them choices. Some of the students become so engaged in the engineering challenge that they question their teacher about when the local water treatment plant will implement their plan.

Research Methods

Participants

For this study, we are using the data of eight middle school classrooms across the Midwest. We collected the data from 1100 6^{th} grade students. For the first research question, the data of the students' who also participated in the assessment of the curriculum unit (N = 915) were considered. Table 1 shows the gender and ethnicity information of the participating students.

Table 1

Gender and Ethnicity information of the students

	No. of Students
Gender	
Male	523
Female	568
Did not Answer	9
Ethnicity	
American Indian or Alaskan	74
Asian American	12
Black or African American	96
Hispanic or Latin	97
Native Hawaiian	2
White or European American	540
Two or more races	137
Others	125
Did not answer	17

Procedure and Instruments

To collect the data, we used an engagement survey to measure students' engagement and specifically designed assessment tests to measure students' performance in a pre-post manner.

For students' engagement, the modified multidimensional engagement instrument, "The Math and Science Engagement Scales" [30] is used, which was validated for middle school students [31]. The instrument has four dimensions, which are behavioral, emotional, cognitive, and social. The survey has items for all four types of engagement constructs, i.e., Behavioral (7 items labeled as Behavior1 – Behavior7), Emotional (6 items labeled as Emotion1 – Emotion6), Social (6 items labeled as Social1 – Social6), and Cognitive (6 items labeled as Cognitive1-Cognitive6). We administered this survey using the Qualtrics system [32] at all schools. Students rated their engagement on all 25 questions on a 5 – Likert scale, where one indicates "Not at all like me," and 5 indicates "Very much like me." To ensure consistency, we reversed coded all negatively worded questions (12 questions – last three items in each type). Table 2 shows the sample items from the survey.

Table 2

Sample items from the engagement survey

Dimensions	Sample Items
Behavioral	• I stay focused in science classes. • If I do not understand a task in science, I give up right away. (R)
Emotional	• I feel good when I am in science classes. • I do not want to be in science classes. (R)
Cognitive	• I try to connect what I am learning in science classes to things I have learned before. • I would rather be told the answer in science than have to figure it out myself. (R)
Social	• I work with classmates to come up with ways to solve problems in science classes. • When working with others in science, I do not share my ideas. (R)

To assess students' performance, we designed an assessment test comprising of 7 MCQs and six open-ended questions. All questions were graded based on the specially designed rubrics. In the assessment unit, we designed the questions to keep the blend of medium to moderately high difficult questions. Table 3 shows sample questions.

Table 3

Sample assessment questions - 6th grade

Type of Question	Sample Questions
MCQ	• Which of the following statement is TRUE about competition between organisms? a) Animals are the only organism that compete for resources b) Plants are the only organisms that compete for resources c) Neither plants nor animals compete for resources

		d) Both plants and animals compete for resources • Fish can be the energy source for which biotic factor? a) Snakes b) Oak trees c) Eagles d) Frogs
Open-Ended		• Explain why it is important for dead animals and plants in the pond system to be broken down. • If all of the small fish in the pond died one year due to water pollution that killed only the small fish, what would happen to the algae in the pond? Explain why you think so.

We conducted the assessments in pre and post manner across all schools. For each MCQ, the students could get a score of one for a correct answer and zero score for an incorrect response. For each open-ended question, we specifically designed rubrics, which could help the graders to grade these questions. The students could score one score for a correct response, 0.5 for a partially correct response (which has some correct aspects but overall does not provide a complete answer), and zero for an incorrect response. In this way, students could score a maximum of 13 marks.

To answer the first research question, we used students' pre-engagement survey results. For multiple regression, we took the average of all items in each dimension (behavioral, emotional, social, and cognitive) independently and used them as independent variables. We used the pre-assessment total score as a measure of students' prior performance and post-assessment total score as a dependent variable. To answer the second research question, we used both pre and post surveys.

Analysis

We used IBM SPSS Statistics 25.0 [33] for our analysis. To analyze the data for the first question of pre-engagement participation in predicting students' performance in the curriculum unit, we used multiple regression analysis. Further, we used the multivariate repeated measures ANOVAs for determining the change in each dimension of engagement post students' involvement in Integrated STEM-based teaching practices. We used the within-subject design of the repeated measures ANOVA and based our results based on time factor (Pre and post surveys).

We also checked for statistical assumptions for both regression and ANOVA. We tested the linearity assumption using scatter plots. Multicollinearity in the data is verified, using the multicollinearity diagnosis variable - Variance Inflation Factor (VIF). We found little or no multicollinearity between predictor variables.

For the assessments, we used multiple graders to grade the open-ended questions and established the inter-rater reliability between graders using Cohen Kappa, which ranged between .651 to .752, shows a good agreement [34].

Results

RQ1: To what degree does students' pre-engagement predict students' performance in the curriculum unit while accounting for students' prior performance?

To answer the question, we used multiple regression for determining the participation of students' pre-engagement in predicting students' performance in the post-assessment test. We also accounted for students' prior performance by using the result of their pre-assessment.

Table 4 shows the summary of regression analysis conducted to predict students' performance post engagement in an integrated STEM-based curriculum unit.

Table 4

Regression analysis summary of students' engagement predicting performance

Variables	*B*	β	*SE*	*t*	*P*	sr^2
Behavioral	.733	.147	.196	3.743	.000**	.010
Emotional	-.214	-.055	.141	-1.515	.130	.002
Social	.329	.074	.151	2.178	.030*	.003
Cognitive	-.219	-.052	.169	-1.299	.194	.001
Prior-Performance	.500	.551	.025	19.927	.000**	.278

*$p<0.05$, **$p<0.01$

The results indicate a significant regression $F(5, 909) = 103.981$, $p= .000$ with $R^2 = .364$. The results showed that the 36.4% variance in students' post-assessment scores is accounted for by the four dimensions of engagement while accounting for their prior performance. Also, the results indicated that students' post-performance in assessment could be predicted using the following equation:

Post-Assessment = .733 (Behavioral Engagement) - .214 (Emotional Engagement) +.329(Social Engagement) - .219 (Cognitive Engagement) + .500 (Prior-Performance) + 1.625.

The summary results indicate that students' prior performance, behavioral engagement, and social engagement are the significant predictors of their performance in the post-assessment. The results also show that students' prior performance is the most significant and largest contributor in R^2 change with = .278. Considering that the other unique contributions of the predictors, as explained by sr^2, are smaller, use, and we have a relatively large sample size, we looked at a decreased significance level. We found that students' prior performance and behavioral engagement are significant predictors with 0.01 level of significance.

RQ2: How does students' engagement change with the use of Integrated STEM-based teaching practices and curriculum?

For the second research question, and to determine the change in students' engagement after compared to before engaging in Integrated STEM-based teaching practices and curriculum, we used the students' self-reported evaluation of engagement. The students reported their engagement in pre and post manner. To conduct the analysis, we used multivariate repeated measures ANOVA for the different types of engagement (behavioral, emotional, social, and cognitive) and time of survey conduction (Pre Survey and Post Survey).

We used Mauchly's W test of sphericity. For the epsilons (ε), which are estimates of the degree of sphericity in the population, we used the criteria of 1.0. for our results. We used the time-based estimates, and the sphericity was not violated. Table 5 indicates the results of repeated measures ANOVA.

Table 5

Repeated Measures ANOVA for Pre-Post Changes in Engagement Factors

	Pre Mean	Post Mean	Mean Difference	$F(1, 1099)$	p	Effect Size (η^2)
Behavioral	4.199	4.080	.119**	39.170	.000**	.034
Emotional	4.156	3.900	.256**	139.773	.000**	.113
Social	4.100	4.049	.050*	5.289	.022*	.005
Cognitive	3.935	3.758	.177**	65.388	.000**	.056

*$p<0.05$, **$p<.01$*

The results indicate a significant change in Behavioral, Emotional, Social, and Cognitive engagement of students from their pre levels of engagement to post level of engagements. Also, on an item by item analysis, all of these engagement dimensions except Social shows a decline. In social engagement, For items 1, 2, and 3, there was an increase in students' evaluation of engagement from pre to post evaluation. Overall, the results indicate a significant change in students' behavioral, emotional, and cognitive engagement post being involved in engineering design integrated curriculum units.

Discussion

Existing literature on STEM education emphasizes the importance of engagement as a contributing factor in students' academic performance, especially for middle school students [2]. Studies have elaborated on the role of engagement in several STEM courses of middle schools and have suggested it as a way to enhance students' abilities for becoming a life-long learner [35]–[37]. Considering the role of engagement and being a critical factor in students' academic performance, in this study, we introduced and used a challenging teaching practice based on the Integrated STEM curriculum unit. We introduced the unit to 6^{th}-grade students and focused on two aspects 1) the role of students' pre-engagement in predicting their performance in a life science curriculum unit. 2) Change in students' engagement after being taught using integrated STEM-based teaching practices. We modified an engagement instrument [30] for the life sciences and engineering curriculum and used these modified scales in pre and post manner. This multidimensional instrument helped us to evaluate engagement on four different dimensions, which are behavioral, emotional, cognitive, and social engagement.

For the first research question, we used multiple regression with four dimensions as independent variables. We also accounted for students' prior-performance, which was measured through a pre-assessment test. We used the results of the students' post-assessment test as the dependent variable. Our results showed that students' prior performance is the most significant contributor in predicting students' academic performance in the post-assessment. However, in addition to prior performance, students' behaviors and social engagement also showed a significant contribution. These results confirm the existing studies on various age groups, which showed that engagement could have an impact or role in predicting students' achievement [38]–[40].

In the second research question, we used multivariate repeated measures ANOVA to understand the changes in students' engagement after they were taught using Integrated STEM-based teaching practices and curriculum units. Our results, contrary to existing research [41], [42], showed a decline in students' engagement on all scales except three items of social engagement. These results are exciting as we used engagement as a multidimensional construct and did not evaluate it on one aspect. For example, most studies have used the Student Engagement Instrument (SEI), which is designed to measure cognitive and emotional engagement only [43]; the social aspect was not a measured factor. Also, the instrument based variation can be another reason for such results. Also, we have very few studies conducted on the life sciences curriculum which evaluate such results.

The current study has few limitations, and results may be viewed and interpreted in light of the following limitations. First, the present study is based on only one grade level (6^{th} grade) of middle school. Second, we used an engagement instrument where students self-reported their engagement. In the absence of other process data such as classroom observations and teachers' reports about students' engagement, the results may have an inflation effect or inaccuracies due to the self-report effect. Third, students were introduced to only one curriculum unit, so the study is limited by exposure to one environmentally theme unit. Also, in this study, we controlled for students' prior performance only, and there can be other confounding variables that can be a venue for future studies.

Based on the results and limitations of the study, we see several future directions and research possibilities. This study is part of a more extensive longitudinal data set and was based on 6^{th}-grade students only. Future studies can focus on other grade levels, such as $seven^{th}$ and $eigh^{th}$-grade students, and their achievements and performance. In this study, we used multiple regression to evaluate the role of students' pre-engagement and prior performance on post-assessment results. Future studies can use structural equation modeling to study the effect of engagement on students' academic performance, and performance post studying using novel Integrated STEM-based teaching activities. Such analysis will also account for the chances of inflated results due to the large sample size and relatively small effect sizes. As discussed in limitations, future studies may also incorporate information from other process data such as classroom observations or teachers' reports of student engagement. Such process data may shed light on these results in better ways. Also, in future studies, we can focus on introducing more than one curriculum unit related to other life science content, which may have reflected changes differently.

Conclusion

Changes in the vision of science education and policy documents indicate the need for providing students an opportunity to engage in innovative and challenging teaching practices [44]. One suggested mechanism is to introduce Integrated STEM-based teaching practices and curriculum units in the K-12 space [44]. Although many studies have focused on introducing engineering design-based curriculum units in mathematics and science education [3], [21], [28], [45], there are limited studies that integrate such practices in the life sciences curriculum [24]. In this paper, we focused on introducing an integrated STEM-based curriculum unit through challenging teaching practices for 6^{th}-grade students. We studied the impact of such integration on students' engagement, for which we used a multidimensional engagement instrument [30]. To do so, we answered two specific questions. Although students are engaged in the Integrated STEM curriculum, what is the role or students' prior engagement and performance in predicting their performance post studying in a challenging and novel way? Also, we focused on determining the change in students' engagement post studying the Integrated STEM curriculum.

Our results indicated a significant impact of both engagement and prior success on students' post-performance. Also, the study results indicated a positive impact on some social aspects of engagement. However, we observed a decline in students' engagement post participating in an integrated STEM curriculum.

The findings of this study are significant and novel. They advance the engineering education literature in a couple of ways, including one of the few studies that incorporated an intervention on life sciences at the middle school level. Also, this is amongst the very few studies which use a multidimensional engagement instrument. We validated this modified instrument in a previous study [31].

Acknowledgment

This study is based upon work supported by the National Science Foundation under Grant No. 1721141 titled "Integration of Engineering Design and Life Science: Investigating the influence of an Intervention on Student Interest and Motivation in STEM Fields." Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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