Effect of Integrated Life Science Units on Middle School Students' Engagement

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Abstract

This research to practice paper explores the effect of an integrated life sciences unit on middle school students' engagement. Prior research on middle school students' engagement provides the evidence of two primary findings: 1) students' engagement in STEM courses shows a decline over time, and 2) students' engagement can be enhanced by providing opportunities to experience meaningful learning. Considering the role of engagement in STEM as a critical factor for developing students' interests in STEM concepts and their selection of STEM-related majors in college, we designed and implemented a life sciences curriculum unit (integrated with engineering design principles) for 6th-grade students. We used the modified engagement instrument, "*The Math and Science Engagement Scales*" to measure students' engagement in 6th-grade classes. We modified the instrument for science classes only. The instrument was executed in pre and post manner to evaluate the change in students' engagement in a multidimensional construct that includes behavioral, emotional, cognitive, and social constructs. More specifically this study addressed two research questions: 1) what is the relationship between the observed measures of engagement items and their constructs? 2) How do students' engagement change as a result of engaging in an engineering design-based life science curriculum unit? The data were collected from 287 students from two middle schools. We used confirmatory factor analysis to validate the instrument for science concepts and used multivariate repeated measures ANOVA to evaluate the changes in students' engagement from pre to post-implementation. After two modifications in the initial model, the results show an adequate confirmatory model indicating the validated relationship between observed measures of engagement items and their constructs. The results of multivariate repeated measures ANOVA indicated that students' behavioral, cognitive, and emotional engagement increased as a result of engaging in the integrated engineering design-based life science curriculum unit. The results also showed the nonsignificant mean difference in the social construct of engagement. The study discusses the results in light of previous literature evidence and provides future directions of research.

Introduction

Enhancing students' engagement in STEM courses is one of the key areas of educational research. Prior studies have shown students' engagement positively relates to the students' participation, motivation, attention, and interest toward the subject that they are learning [1]. Enhancing student engagement requires instructors to provide two kinds of experiences to students: 1) keeping them active in classes, and 2) providing authentic connections to learning so students can make sense of the subject [2]. Further, students engage when they put effort, spend time [3], and willingly participate [4] in the educational activities to get the desired learning outcomes [5].

Taking into account the aspects of keeping students active and providing authentic connections, this study followed the Integrated Engineering Design approach [6], [7] to design a middle school curriculum. Engineering design-based activities and practices have proven to engage students in science education effectively, but there is a lack of literature using engineering design in life sciences courses. Considering this lack of research and integration, our research team developed curriculum materials for integrating engineering design where the existing units of the life sciences curriculum were modified to center around a design challenge and incorporate engineering design principles. The study used teaching science and engineering in an integrated manner to subsequently explore students' learning outcomes and engagement (behavioral, emotional, cognitive and social). In this paper, we present the effects of these designed curricula on 6th-grade students' engagement.

More specifically the study is guided by two research questions:

1) What is the relationship between the observed measures of engagement items (~25 items) and their constructs?
2) How do students' engagement change as a result of engaging in engineering design – based life sciences curriculum unit?

This study is part of a larger longitudinal study that is being conducted in multiple middle schools located in the Midwest of the United States. The study presents the findings of the validation of the instrument used to evaluate students' engagement and results of students' engagement change as a result of the pilot intervention in the first year of the project.

The paper is characterized in six sections. Section II reviews the existing literature on middle school engagement. Section III provides an overview of the curriculum unit followed by the research design and methods of the study, results, discussion, and conclusion section . The discussion section also includes the limitations and conclusion section discusses future directions.

Literature Review

Student engagement was first conceptualized in 1985 by Mosher and McGowan, and they reported that "engagement" as a term was rarely mentioned in the existing literature [8]. To address the gap, Mosher and McGowan [8] defined the conceptual framework of engagement and established its impact on students outcomes including achievement and behavior. Since the inception of the literature, engagement is characterized as a multidimensional construct. Some researchers described engagement as a "meta construct" with an embedded meaning of participation, motivation, and self-efficacy [9], while others argued that engagement is a construct with its defined boundaries and dimensions [10]. In general, the literature shows three aspects of engagement, namely behavioral, emotional, and cognitive [1], [8], [9], [11]. Behavioral engagement is based on academic and social participation such as credits earned, homework completion rates, attendance in class, events attended, participation in extracurricular activities, etc. [12], [13]. Emotional engagement is based on affective measures of interactions in school, both in positive and negative manners. These interactions can happen with parents, teachers, peers, school, etc. [13]. Cognitive engagement is based on the willingness to put effort into understanding and mastering the concepts. Cognitive engagement requires self-regulation, motivation, and mastery approach [9], [13].

Existing research provides evidence on the study of these three aspects and its effect on various other measures. For example, some studies used the engagement construct as a way to understand students' retention and dropouts rates [14]–[18], students' success in school such as adherence to school rules, perform better, and seek higher education [19]–[21], student belongingness and participation [22], [23], enhancing self regulation [24], [25] , and enhancing students' motivation to learn [26], [27]. Literature also has evidence that these studies mostly measured only one or two aspects of school engagement, and have ignored the other aspects [28]–[30]. Also, these studies lacked a description of the process or mechanism of increasing student engagement. Further, most of these studies have used the Student Engagement Instrument (SEI) which is designed to measure cognitive and emotional engagement [12], [31]. However, these studies have not used the fourth aspect of engagement described as "social or community engagement." Social engagement is defined by one's active participation in a social group or team, social roles and relationships [32] through interaction with other members and commitment to remain part of the group [33]. Prior research focusing on enhancing middle school students' engagement also used a similar approach, and utilized one or two aspects of engagement, or have studied engagement as a general construct.

Prior studies have used various interventions to enhance students' engagement in science and mathematics courses, such as the use of video games [34], project-based approaches [35], or other technology-based interventions [36]–[38]. The use of engineering principles, the design of hands-on engineering activities, and integrating engineering design in the curriculum were also used as an intervention in science [39]–[42] and mathematics [43] courses which resulted in enhanced student engagement. For example, English and colleagues [44] incorporated an engineering design based activity for 8th graders, and they explored students' ability to make the connections between concepts, materials, constraints and connection process. The authors reported both the students and the teachers' perspectives on the effectiveness of the activity. The students showed their satisfaction on the activity and found that the activity kept them engaged, helped them to understand the importance of collaboration, and design constraints. The teachers found that the activity was effective to enhance students' engagement. Also, teachers found that their collaborative work with peers to develop the activities was effective and engaging. Although such studies are available for science and mathematics, the literature lacks evidence of such integration of engineering design in life sciences courses for middle school students [45], which describe the need of current study of engineering design integration in life sciences and exploring its effect on students' engagement.

Overall, considering the lack of studies on middle school student learning of life science concepts through engaging in engineering design and practices, there is a need to conduct more research studies. Also, it is equally important to study engagement as a multidimensional construct with its all four aspects (behavioral, emotional, cognitive and social). Wang et al. considered capitalizing on the multidimensional conceptualization of engagement. They provided a validated self-report based engagement measurement instrument that takes multidimensional perspective and consequence of all four types of engagement into account especially to address the domains of mathematics and science. This study is designed to address all these research gaps and is based on 6th-grade students. Students were taught a science course with an integrated engineering design curriculum unit. We used the tailored version of "The Math and Science Engagement Scales" [46] and measured all four aspects of engagement. The curriculum unit was designed by the project team and is discussed in the next section.

Life Science Unit

We designed the engineering-driven life science unit for the 6th-grade science classroom. The unit was built around understanding, design, and implementation of engineering activity. The unit required students to learn the content they would need to design and build a two-stage water filter. The designed unit was to complete in five lessons, where each lesson could take from two to five class periods (45 minutes each). Table 1 shows the five lessons, their objectives, and the anticipated number of classroom days for each lesson. The context of the unit is the combined sewer overflow problem, which can lead to the pollution of rivers. The project team purposefully selected this context and the design challenge to make the engineering design engaging for *all* students.

The design task of the unit asks students to design a water filter to help prevent the pollution of a local river. Simply put, in an intense rain, stormwater discharges directly to the local river without being treated by the wastewater treatment plant because of an overwhelmed combined sewer overflow (CSO) system within the city. The unit 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 system for the city's wastewater management plant. 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.

Table 1 Overview of the unit

Lesson	Objective	Timeline
Lesson 1: Introduction to the design challenge	Introduce engineering design task, client letter and a short video from an engineer from the city's wastewater management plant, and engineering design process	Days 1-2
Lesson 2: Water cycle and soil percolation	Describe the effects of abiotic factors on habitat, water cycle, effects of soil types on the percolation of water	Days 3-4
Lesson 3: What plants need to live	Measure and analyze how living things use abiotic factors	Days 5-7

Lesson 4: Interactions in the ecosystem	Identify the relationship between various organisms in an ecosystem	Days 8-10
Lesson 5: Creating the water filter	Construct a two-stage water filtration system	Days 11-15

We used this integrated engineering design curriculum unit to study our research questions especially the impact this unit made on students' engagement.

Research Methods

Participants

The data were collected from 6th-grade students in two schools located in the Midwest. The study includes data from the students who have completed all the requirements of the study which are a pre-engagement survey, pre-content test, post-content test, and post engagement survey. This study includes two different sample sizes for both research questions: for the first research question (i.e., the validation of instrument), data includes surveys from 287 students which includes participants from both baseline and pilot years of the study. We specifically used both baseline and pilot data since the validation of the instrument does not require the implementation of curriculum units in an integrated manner. For the second research question, we have used data from 69 students who participated in the pilot implementation of the curriculum units. We excluded data from the baseline year for the second research question since there was no intervention during the baseline year.

Table 2 shows the demographic information (gender and ethnicity) of the students. Although two students' didn't mention their ethnicity, their data is included in the sample due to the completion of the study requirements.

Table 2 Demographics information of the students

	No of Students
Gender	
Male	123
Female	164
Ethnicity	
American Indian or Alaskan	21
Asian American	3
Black or African American	6
Hispanic or Latin	26
Native Hawaiian	1
White or European American	179
Two or more races	26
Others	23
Didn't answer	2

Procedure and Instruments

We used an engagement survey in a pre-post manner to determine changes in students' engagement. The survey was the extracted version of students' self-report of engagement scales [46]. 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). The survey was administered using the Qualtrics system [47] at both schools. Students answered all 25 questions on a 5 – Likert scale ranging from 1-Not at all like me to 5- Very much like me. Before conducting the study and running any model, the negatively worded questions (12 questions – last three items in each type) were reverse coded for consistency.

Analysis

We used IBM SPSS Statistics 25.0 [48] for descriptive statistics, correlation matrix, and also for repeated measures ANOVA. Additionally, we used LISREL 9.30 [49] for conducting the Confirmatory Factor Analysis (CFA).

For the first research question, the CFA was used as is a confirmatory technique to validate the instrument supported by logic and theory. As the version of the instrument is already validated in the original study [46]. CFA appeared as the most appropriate technique which allows testing the existing hypothesis of a relationship between observed variables and their latent constructs [50]. To test the model of CFA, multiple goodnesses of fit indices were considered to evaluate the fitness of the model which include Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Incremental Fit Index (IFI). According to the literature the values of above 0.90 for CFI, IFI are indicative of good model [51], and values above 0.85 indicate an adequate fit [52]. Also, the values of RMSEA below 0.10 is adequate [53] with a good fit being with values below 0.08 [51]. In addition, we used the criteria of significant factor loadings with standardized coefficients above 0.30.

For the second research question of how students' engagement change as a result of experiencing integrating engineering design in life sciences unit, we conducted repeated measures ANOVA on the engagement survey modified for science classes for all four aspects of engagement.

Results

RQ1: The relationship between the observed measures of engagement items and their constructs

The descriptives statistics and factor reliabilities of the data were calculated. The results of the constructs of the survey are presented in Table 3 for 6^{th}-grade students. The factor reliabilities were calculated using Cronbach's alpha. The descriptive statistics are based on item-based statistics.

Table 3 Descriptive statistics of the survey constructs for 6^{th} Grade

Constructs	Reliability	Mean	Variance	Min	Max
Behavioral	.733	4.142	.880	3.822	4.456
Emotional	.896	3.827	1.299	3.324	4.523
Social	.761	4.143	.919	3.774	4.502
Cognitive	.785	3.798	1.087	3.544	4.108

The CFA model was created on 6th-grade students to evaluate the extent to which the hypothesized model was a good fit to the observed data using a priori that: a) response to engagement can be explained by four factors; b) each item would have a non-zero loading on the burnout factor it was designed to measure, and zero loadings on all other factors; c) the four factors would be correlated; and d) measurement error terms would be uncorrelated. All analysis was based on covariance matrices. The analysis in this study was run to explore the goodness of the fit of the model.

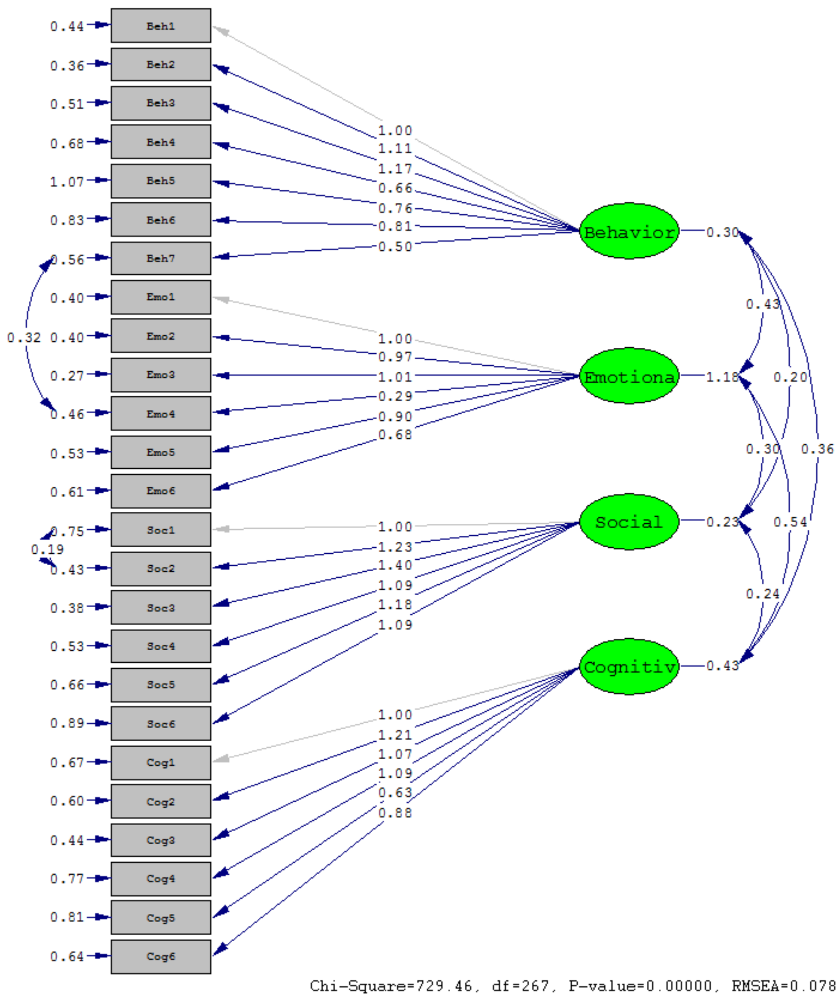

Figure 1: CFA model of the 6th-grade engagement survey

Preliminary analysis indicates that all factor loading, factor variances, covariance, and error variances are significant at $p < .05$. In addition, the goodness of fit statistics indicated the significant and higher value of chi-square $\chi2(269) = 879.715$, $p = 0.000$ which is an indication of not a very adequate model. The Incremental Fit Index (IFI) = *0.819*, and the Comparative Fit Index (CFI) = *0.817* are less than 0.85, which indicates the absence of a good model. Although Root Mean Square Error of Approximation (RMSEA) = *0.0889* were under 0.10 but were greater than 0.08. Overall the model indicated not a good fit and indicated modification for improvement.

Based on data items, and the results of the first model, we decided to estimate an error variance between emotion4 and behavior7 items (both are reverse coded). With the analysis, the model although improved but further modification was essential. The model was further improved by the estimation of error variance between social2 and social1. The results indicate that with this change, the chi-square values were decreased, which indicates an improvement in the model with $\chi2(267) = 729.459$, $p = 0.000$. The values of RMSEA = *0.0777* indicated an improvement in the model. The value of the Incremental Fit Index (IFI) = *0.863*, and Comparative Fit Index (CFI) = *0.862* > 0.85 were all increased from the previous models. Considering these values, the third model shows changes to an adequate fit. **Error! Reference source not found.** indicates the fitted CFA model.

RQ2: Changes in students' engagement as a result of experiencing integrating engineering design in life sciences unit.

To answer the second research question, as the engagement survey was conducted in a pre-post manner, we used repeated measures ANOVA for all 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. The epsilons (ε), which are estimates of the degree of sphericity in the population, were less than 1.0, indicating the sphericity assumption is violated. To adjust the degrees of freedom, if epsilon was <0.75 we used Greenhouse-Geisser epsion, and Huynh-Feldt epsilon otherwise. Table 4 indicates the results of repeated measures ANOVA.

Table 4 Repeated Measures ANOVA for Pre-Post Changes in Engagement Factors

	Mauchly's W	Epsilon (ε)	df	χ^2	Mean Difference	Effect Size (η^2)
Behavioral	.475	.877	20	48.901**	.166**	.144
Emotional	.324	.762	14	74.461**	.198*	.480
Social	.340	.683	14	71.279**	.024	.112
Cognitive	.565	.882	14	37.749**	.150**	.169

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

Huynh-Feldt values indicate that three factors behavioral with $F(1,68) = 9.020$, $p = .004$, emotional with $F(1,68) = 5.411$, $p=.024$, and cognitive with $F(1,68) = 7.309$, $p=0.009$ shows the significant positive mean difference between pre and post survey. The social factor was adjusted with Greenhouse-Geisser epsilon, $F(1,68) = .112$, $p=.739$ showed a nonsignificant mean difference between pre-survey and post-survey.

Overall, the results indicate a significant positive change in students' behavioral, emotional, and cognitive engagement post being involved in engineering design integrated curriculum units.

Discussion

Prior studies describe the role of engagement in mathematics and science classes as a critical factor for students' academic performance, as well as for the selection of STEM-related majors and professions at their later careers [54]. In this study, we designed and implemented an engineering design integrated life sciences curriculum unit and studied the effect on 6th-grade students' engagement. To evaluate students' engagement, we used a modified engagement instrument, "The Math and Science Engagement Scales" [46] which we modified for science classes only. The engagement survey includes behavioral, emotional, cognitive, and social constructs. We used this instrument in pre and post manner to address two research goals: 1) to evaluate the validity of the instrument, and 2) to evaluate the changes in students engagement post attending the curriculum unit.

For our first research question, we used confirmatory factor analysis to validate the survey. Our results indicate an adequate fit of the model after two modifications, and we reverse coded each negatively worded question so that all items have the same scale for measurement. CFA confirmed that our chosen and modified science engagement items have four unique dimensions titled as behavioral, emotional, cognitive and social. These results align with the results of the original study [46]. In the original study, instrument validation was conducted using 2nd order CFA separately for the positively worded question and negatively worded questions, bifactor model fit, and later structural equation modeling techniques to predict students' achievement.

In the second research question, we used repeated measures ANOVA to determine the changes in student engagement post studying the integrated life sciences and engineering design curriculum unit. Our results indicate a significant and positive mean difference between pre and post analysis. These results also align with research on mathematics and science integrating engineering design principles or activities in classes [40], [55]. The result of these existing studies showed that if students are taught using an authentic problem with the integration of science, technology, and other aspects, are better engaged, and evolve as a critical thinker.

The current study has few limitations and results may be viewed and interpreted in light of the following limitations. First, the present study is limited by a relatively small sample size specifically for the second research question (i.e., 69 students), but as this study is exploratory, this sample provides the preliminary findings of changes from pre to post engagement after engineering design is integrated into life sciences units. Second, this study used the instrument which relies on students' self-reports of engagement, which may cause an inflation effect or inaccuracies due to the self-report effect. The other sources such as instructor reports/evaluations of students' engagement or interviews with students about engagement could be other future sources. However, prior literature also indicates that students' self-reports are valid indicators of their abilities [56], [57]. Third Wang et al. [46] also suggested that the bifactor model indicates a better fit model than CFA and although we found an adequate fit of the model after two modifications, we may also consider other techniques on larger data sample to verify the results. Fourth the context of the study was limited by introducing one environmentally themed integrated engineering design based life science curriculum unit to 6^{th} graders. We although found that students' engagement change as a result of the intervention; this is a venue of future studies.

Conclusion

Engineering design and practices are essential elements in a new vision of science education, and recent policy documents expect to engage K-12 students in scientific and engineering practices [58]. With this new vision, it is especially important to incorporate engineering design into the middle school curriculum. Keeping in view, we introduced engineering design to teach life sciences concepts for building a more robust and thorough understanding.

In this study, we studied the effect of integrating engineering design into life science curriculum units on students' engagement. We modified the engagement instrument "The Math and Science Engagement Scales" [46] for science classes only and collected the data in pre and post manner. As we modified the instrument, our first research question targetted the validation of a modified instrument using confirmatory factor analysis. The result indicated an adequate fit of the model. The second research question addressed the changes in students' engagement post implementing the curriculum unit and pre and post students' survey. We used repeated measures ANOVA to study the effect and found a positive impact on students for behavioral, emotional and cognitive factors. The mean difference of social factor was not significant.

The findings of this study are significant and describe the contribution to literature as this study is one of the very few studies which incorporated an intervention on life sciences at the middle school level. Existing literature has a lot of evidence on science and mathematics, but the evidence in these research studies was inconsistent in terms of the definition of engagement and also on how to measure student engagement [46], [59], [60]. Furthermore, such literature was not widely available on life sciences curriculum except a study conducted by Guzey and colleagues [45]. This study is one of the few studies on engineering design integration in the life science curriculum. Further, this study enhances the literature by providing the evidence of studying engagement from four multidimensional aspects and has used an instrument which was explicitly designed for mathematics and science and was modified for science content only.

With the result of this study, there are some future directions. First, this study was conducted on the data of the first year of the project and is part of the larger longitudinal study. Thus, more studies may be designed with a larger sample to confirm the results of both research questions with a larger sample size. Second, the CFA invariance studies may be designed between 6th, 7th and 8th-grade students on the modified instrument to describe better results of instrument validation. Third, with a larger sample size, we may also replicate the bifactor model as in an original study bifactor model found better fit model. Furthermore, structural equation modeling can be used in to study the effect on engagement on students' academic performance by using the specifically designed assessment for the curriculum.In addition to students' self-reports of engagement, classroom observation data or teachers reports about students' engagement can be used to understand changes in students' engagement. Finally, future studies may explore the impact on integrated engineering design-based curriculum units on middle school students using more than one intervention.

Acknowledgment

This study is based upon work supported by the National Science Foundation under Grant No. 1721141 titled as "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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