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Integrating Biology and Mathematics Using IMS-TEAM Framework

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Abstract

STEM education is on demand more than ever as the workforce relies on 21st century skills and STEM disciplines. This paper presents a framework (IMS-TEAM) for integration of mathematics and science with the use of technology and modeling in an authentic context. The activity based on this framework is designed for and implemented with forty-four 8th grade students in Turkey. The study was conducted to investigate the impact of the activity as well as the IMS-TEAM framework. A qualitative methodology was utilized. Data analysis revealed that different components of our conceptual framework fostered the integration of mathematics and science affecting the nature of students' engagement with the activity. Different frameworks are required to be adapted to different environments with the consideration of learners and teachers. Future research investigating the effectiveness of IMS-TEAM framework adapted to different content and disciplines would provide more evidence on the effectiveness of the framework.

Keywords: STEM Education, Science Education, Mathematics Education, Technology, Modeling

Introduction

Today's technology and innovation driven economy more than ever leads to the need for STEM literacy. Based on this need, STEM careers are primarily on demand. Moreover, reports published by the Executive Office of the President (2018) and U.S. Department of Education (2016) state that STEM literacy should not be limited to only STEM careers but a necessity for all citizens. However, several reports and studies raise concerns regarding the lack of interest for STEM careers and strongly advocate for initiatives for STEM education to resolve this issue (Bøe, Henriksen, Lyons, & Schreiner, 2011; DeWitt & Archer, 2015; OECD, 2017; Regan & DeWitt, 2015; U.S. Congress Joint Economic Committee, 2012).

Integrated STEM education is considered to be one of the ways to provide students with learning opportunities where they can develop 21st century skills, such as problem solving and critical thinking skills (Akgun, 2013; Executive Office of the President, Office of Science and Technology Policy, 2018; Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018; Wong & Huen, 2017). Before we discuss the benefits of STEM education, we need to share what we mean by STEM education. STEM education could be interpreted differently by many people. One of the interpretations defines STEM education as isolated individual STEM subjects such as mathematics or biology only (Breiner, Harkness, Johnson, & Koehler, 2012). In time, the definition of STEM education has evolved from "a set of overlapping disciplines into a more integrated and interdisciplinary approach to learning and skill development" (Executive Office of the President, Office of Science and Technology Policy, 2018, p. 7). We interpret this latter definition as integrated STEM education and the framework proposed in this paper centers around this definition. Considering the compartmentalized nature of teaching content areas such as science and mathematics, we believe an integrated STEM education framework could present a good opportunity to make meaningful connections between disciplines. However, research points to a lack of meaningful connections between science and mathematics (Bing & Redish, 2009). Science taught in an isolated nature would limit its interpretation and may hinder students' understanding of the real-world scientific concepts. Zhao and Schuchardt (2021) state that "Math-Concept sensemaking in science classrooms is relatively underexplored" (p. 12). Researchers also state that the integrated approach presents a holistic learning leading to efficient student learning, problem solving skills, and critical thinking as well as innovation (Executive Office of the President, Office of Science and Technology Policy,

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2018; Furner & Kumar, 2007; Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018; Stohlmann, Moore, & Roehrig, 2012; Thibaut et al., 2018; U.S. Department of Education, 2016). Other benefits of integrated curricula include positive student attitudes, increased motivation, and other affective learning outcomes (Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018; Stohlmann, Moore, & Roehrig, 2012; Thibaut et al., 2018).

This paper presents a part of a larger study where the aim is to provide an example of this kind of meaningful integration between biology and mathematics via an activity utilizing technology. We leverage the understanding of both biology and mathematics where biology provides a context for the mathematics and application of mathematics elevates the interpretation of the biology. The main goal is to uncover some aspects of students' engagement with the integrated STEM activity which was developed using the conceptual framework--Integrating Mathematics and Science with the support of Technology, Engineering, Authentic Tasks, and Modeling (IMS-TEAM) (Schrauben, Özgün-Koca, Edwards, Chelst, & Griffin, 2017). Our research question of the study was: What are middle school students' engagement and reactions to the integrated STEM task designed according to the IMS-TEAM framework?

Conceptual Framework

Integrated STEM education is considered as one of the potential solutions to existing issues of interest in STEM careers as well as student learning of STEM concepts. STEM education literature offers different frameworks for STEM integration using various frameworks either focusing on theory or implementation of STEM (Asunda, 2014; Bybee, 2013; Huntley, 1998; Kelley & Knowles, 2016; Walker, Moore, Guzey, & Sorge, 2018), while, some focuses on putting theory and practice together (Thibaut et al., 2018; Wong & Huen, 2017).

Situated learning theory and social constructivism were among the frequently mentioned theories discussed by researchers when it comes to STEM education frameworks (Asunda, 2014; Kelley & Knowles, 2016; Thibaut et al., 2018). These learning theories provide a base for the pedagogical practices of authentic problem-solving and group work which are crucial for STEM learning. We saw that implementation-oriented frameworks for STEM integration are centered around the project/problem-based learning while highlighting various pedagogical aspects such as effective use of manipulatives (Stohlmann, Moore, & Roehrig, 2012). All of these frameworks have different standpoints in framing the integrated STEM education. This study, introduces a new framework explained below.

The IMS-TEAM Framework

Integrating Mathematics and Science with the support of Technology, Engineering, Authentic Tasks, and Modeling (IMS-TEAM) framework is influenced by two major frameworks by Bybee (2013) and Huntley (1998). As Bybee (2013) suggests, STEM integration should be at a practical level bounded by one's conditions and one should consider their own understanding and conceptions for the integrated STEM approach. In our case, our first step was to analyze both mathematics and science curricula to identify the corresponding concepts and units to integrate mathematics and science content. The current structure of the Turkish national curriculum for both disciplines are very compartmentalized within themselves and do not provide a detailed guidance for integrated STEM education (MEB, 2018a; MEB, 2018b). For instance, the Science, Engineering, and Innovation section in the middle school science curriculum states that "students are expected to identify a real-world related problem or need with respect to the topics from [science] units…then they are expected to find solutions to the problem...present their solutions" (MEB, 2018a, p. 10). As can be seen, the guidance for implementation of integration is not only unclear, but also excludes the mathematics from this integration. This exclusion of mathematics from STEM integration was also noticed by other researchers such as English (2016) and Shaughnessy (2013). Having these in mind and analyzing the Turkish science and mathematics curricula, we identified that our main focus should be on the integration of mathematics and science content and we built our framework around this focus (see Figure 1).

In this framework, mathematics and science content are at the center. The learning outcomes would come from both

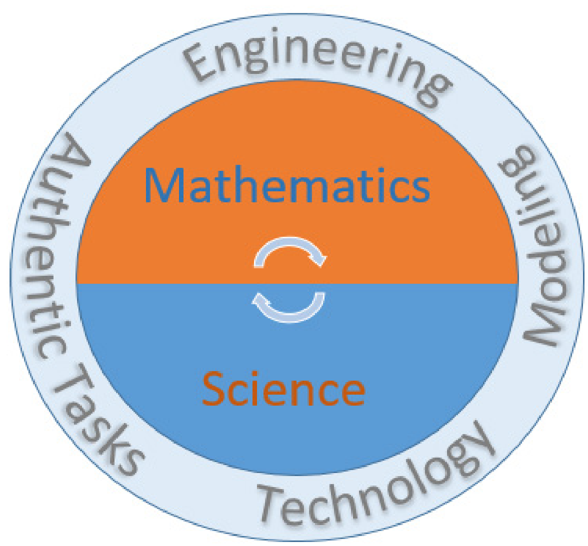

Fig. 1: Conceptual Framework--IMS-TEAM

grade-level appropriate mathematics and science curricula. We highlight the interactive nature of the relationship between mathematics and science with the colors in this framework. The cyclical arrows represent the support that one discipline provides for the learning of the other discipline. Huntley (1998) described a truly integrated mathematics and science activities when "the mathematics (content and methods) and science (content and methods) ...play synergistic roles in explaining the world" (p. 322). This kind of integration of multiple disciplines in STEM education definition has been highlighted by other researchers and educators (Hodges, Jeong, McKay, Robertson, & Ducrest, 2016; Thibaut et al., 2018).

In the IMS-TEAM framework, the potential practices are included in the outer ring. Technology, modeling, the use of authentic tasks, and engineering support and enhance the integration of mathematics and science. The utilization of all of these practices is important but not mandatory and choice of inclusion in the activities depends on the content, time allocated as well as age group specifications.

Technology provides an environment and a platform for the integration of mathematics and science. In our case the technology component of the model was satisfied with the use of sensor and graphing technologies. Using sensor and graphing technologies in STEM education supports students' ability to ask questions, identify a problem, conduct research, collect data, and analyze data effectively. Accordingly, it develops scientific and mathematical reasoning among students as they "translate abstract mathematics and science concepts into concrete real-world applications" (Nugent, Barker, Grandgenett, & Adamchuk, 2010, p. 392). This points to the second practice of the IMS-TEAM framework: the use of authentic tasks. Kelley and Knowles (2016) highlight the importance of using real-world contexts: "students are often disinterested in science and math when they learn in an isolated and disjoined manner missing connections to crosscutting concepts and real-world applications" (p. 1). In our study, the use of photosynthesis data provides authentic data for our activity. The final practices of our framework are the integration of modeling and engineering design. While engineering design focuses on the process of engineering and ties all content together "STEM content, engineering design can become the situated context and the platform for STEM learning" (Kelley & Knowles, 2016, p. 4), modeling allows bridging the classroom mathematics and science to the real-life phenomena. In this study, the use of graphical models bridged the photosynthesis data with mathematics which lacks in the current curriculum. Due to time constraints (classroom time was limited to 80 minutes) the engineering component of the framework was left out from the activity during the classroom implementation; but the IMS-TEAM framework could be utilized for more in-depth integration involving all components. The following sections describe the design process as well as implementation of an activity based on the IMS-TEAM framework mainly focusing on biology and mathematics integration via technology.

Method

Research Design

This study utilizes a qualitative approach to investigate how middle school student engage with an integrated STEM activity which was designed according to the IMS-TEAM Framework.

Participants

This study took place in a public middle school in one of the major cities of Turkey. The school ranking is in the top 10 percent citywide among the public schools. Participants of the study were 44 eighth graders from middle to high socioeconomic status families. 23 students in one class and 21 students in another class.

The reason for choosing to work with middle school students is two-fold. Firstly, middle school science and mathematics curricula present important and suitable content for effective integration. Secondly, early interventions are reported to be effective before students choose content specific tracks especially in secondary school (Executive Office of the President, 2018). Thus, photosynthesis and linear equations from 8th grade science and mathematics curricula respectively were chosen as foci of this integrated STEM activity. The activity integrates biology and mathematics through technology. In the proposed activity, students worked with probeware to collect and view photosynthesis data, used dynamic graphing software to graph and study data and discussed different set up designs to improve effectiveness of the photosynthesis. The length of the activity is two class hours (80 minutes). The design process of this activity was shared in Authors (2020).

Data Collection

The main data collection methods included:

- Open ended questionnaire,
- Student worksheets,
- Video recordings of the lessons,
- Interview with the science teacher, and
- Field notes by the researchers.

An open-ended questionnaire was used after the activity to collect data on students' reactions to the activity. This questionnaire included questions such as:

- What mathematical concepts did you learn as a result of this activity?
- What biological concepts did you learn as a result of this activity?
- Would you want to do more activities like this in the future? Why?

Video recordings and student worksheets were used to observe students' interactions with the activity as well as group and whole class dynamics. The worksheets were also analyzed to study students' individual thinking process during and after the activity. Two researchers took their individual field notes immediately after each implementation. To support researchers' field notes and gain classroom teacher's feedback an interview was conducted with the science teacher of both of the classes.

Trustworthiness

The data is triangulated with multiple qualitative data; video recordings, open-ended questions, student worksheets, field notes and an interview with the science teacher. Preliminary observations were confirmed with the science teacher using the member check method. Therefore, the main methods to obtain the trustworthiness of this study were data triangulation and member check (Guba & Lincoln, 1989).

Data Analysis

The qualitative data sources were open-ended questionnaire, student worksheets, video recordings, the interview with the teacher, and the field notes. The video recordings and the interview were transcribed prior to analysis. And all data were analyzed to identify codes, categories, and themes (Miles & Huberman, 1994).

Findings

The qualitative data were analyzed to explore students' engagement and reactions to an integrated activity with during and post measures. Our primary outcome of the results was that different components of our conceptual framework fostered the integration of mathematics and science affecting the nature of students' engagement with the activity. What we mean by student engagement is the way students interact with the activity, their contributions to the small group work, their contributions to the whole class discussions, and their individual responses to the worksheet. Specifically, we concluded that

- Students were motivated and reported that they enjoyed the activity
  - Students stated that they learned both biology and mathematics.
- All students seemed to be engaged with the activity, even though there were different levels of engagement.

The Use of IMS-TEAM for Science and Mathematics Integration

As shown in Figure 1, IMS-TEAM framework utilized technology, modeling, authentic tasks, and engineering design process to enhance the integration of science and mathematics. Photosynthesis provided an authentic context for this activity. At the beginning of the activity students were introduced to the set-up for the photosynthesis data collection with the probeware. Seeing this set-up supported students as they were interpreting the data. During the activity, all models (table, graph and equation) included variables based on this context and discussions were carried out in connection to the context of the variables. Multiple technologies were used such as probeware and dynamic graphing software to create and study multiple models of the phenomenon. During the activity students worked with photosynthesis data (O_2, CO_2, light intensity, temperature and time) which were collected through probeware (see Table 1 for a sample data).

Table 1: Photosynthesis Data

Time (hour)	*CO2*	*O2*	*Light (lux)*
3	7984	160541	0
6	7631	162242	560
9	7367	165020	1287
12	7207	166540	2965
15	7369	163853	1047
18	7151	162783	91
21	7276	162960	0

Analyzing these values in Table 1, students were asked to discuss the relationships that they observe in the data in small groups. This provided the first opportunity for students to interpret a mathematical pattern in a table of data values to make sense of a relationship in biology. In this section, we will provide data from student worksheets and class discussions to showcase the affordances and limitations of the activity.

Students were asked to interpret data from Table 1 and determine patterns and relationships. Thirty-three percent of the students listed 2 relationships, 31% of them three relationships and 21 % of them one relationship, 5% of them 4 relationships. Ten percent of the students either left the question blank or provided a partial response. The relationships that students identified were:

- Light intensity and O2 (31% among the listed relationships)

- Light intensity and CO2 (29% among the listed relationships)
- CO2 and O2 (22% among the listed relationships)
- Time versus O2 (11% among the listed relationships)
- Time versus CO2 (4% among the listed relationships)
- Time versus light intensity (4% among the listed relationships)

Twenty-six students saw that as the light intensity increases the O_2 values also increase. Twenty-two students stated that as the light intensity increases the CO_2 values decrease. Nineteen students stated that as the value of O_2 increases the CO_2 values decrease. While some of these were separate statements such as: "O_2 level increases as the light intensity increases," "CO_2 level increases as the light intensity decreases," "CO_2 decreases as O_2 increases," and "O_2 level decreases as CO_2 increases." Some of the students were able to state multiple relationships with one sentence within the context: "As the light intensity (lux) increases, O_2 in the air increases, CO_2 in the air decreases." Students were also able to interpret the nature of the relationship based on the observed data. This highlights the importance of using mathematics to unpack the relationships in scientific context, in our case photosynthesis context.

Photosynthesis is an abstract topic and if the relationships between variables are presented without any data or a lab, students might tend to interpret these relationships without understanding. However, in this activity, structured with the IMS-TEAM framework, the biology content was extensively integrated with mathematical models which allowed students to be able to discover relationships using mathematical models. The data collected during photosynthesis with probeware were more extensive than presented and an instructional decision was made regarding which data to share and in what format aiming to foster student engagement within the activity. We intentionally chose to share O_2, CO_2, time and light intensity data as represented in Table 1 for a 21-hour time period. This tabular and numerical model allowed students to explore multiple relationships without being lost in the data.

Then, we moved to graphical models. Prior to seeing any graphs, students were asked to predict the graphs for the observed relationships from the numerical data; for instance, students in one group were able to gesture time versus O_2 graph as increasing first signaling an invisible diagonal line with a positive slope using their hands and then they changed their line to another diagonal invisible line with a negative slope (see Figure 2a and b).

Here students were able to move from one mathematical model to another (from numerical/tabular model to graphical) within the context of photosynthesis with the help of technology. Students saw if their graphical expectations were accurate when they had access to the graphs with GeoGebra on the board (see Figure 3). Next students were tasked to predict light intensity versus O_2 graph based on the table and the other two graphs (the time versus O_2 graph, and time versus light intensity graph). As mentioned above, the majority of the (twenty-six) students were able to infer from the table that light intensity and O_2 were increasing or decreasing together. They also recognized that the time versus O_2 and time versus light intensity graphs were similar.

Figure 2a. The first part of the graph as time increases O_2 levels increases

Figure 2b. The second part of the graph as time increases O_2 levels decreases

The goal of this part of the activity was for students to predict the linear relationship with positive slope (as can be seen in the equation in red in Figure 3 as well) which points to the fact that as one increases the other increases or as one decreases the other decreases as well. Being able to detect and interpret patterns and relationships in data through mathematical graphs enabled students to use and engage with both mathematical and biology knowledge. However, the major difficulty for some of the students was reflecting on the light intensity and O_2 relationship without the time variable. Twelve percent of the students predicted a similar graph to time versus O_2 or time versus light intensity (see Figure 4a). Another 12% of the students used values from the table to draw the graph as in Figure 4b. Forty-six percent of the students were able to predict the expected linear graph with positive slope as shown in Figure 4c. Twenty-nine percent of the students either left the graph blank or produced an incorrect graph.

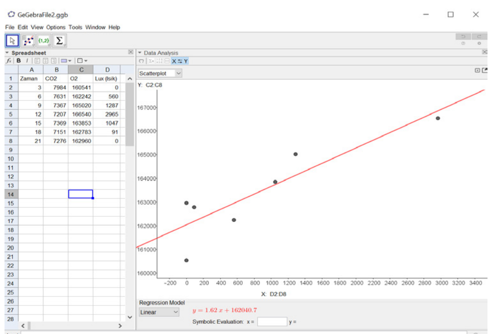

Fig. 3: GeoGebra Screen

As seen in Figure 4b and 4c, students were able to use the available data from the table or use the information from the previous graphs to predict the graph. However, at the end, students as the whole class concluded that O_2 and light intensity relationships was a linear relationship with a positive slope. This relationship between the light intensity and O_2 was discovered by the students based on scientific and mathematical reasoning. This activity designed based on the IMS-TEAM framework provided multiple opportunities for active student engagement. In the next section, we will discuss how this activity reached out to the students at different levels.

Students' Level of Engagement

During the teacher interview, one of the main points addressed by the teacher was that the students' levels of engagement differed from the regular class environment for some students. The teacher observed that some of the most actively contributing students during this activity were considered academically average who are not really active during the regular class environment. During the activity these academically average students demonstrated higher order thinking skills. Meanwhile, one of the high achieving students who also scored in the top one percent in a national standardized test was observed not to contribute to the whole class discussions. In this section, we will focus on four students--one academically average and one academically high achieving student from each class--and their level of engagement in this activity.

Ali and Mehmet (pseudonyms) were categorized as average students not participating in the class discussions in the regular class environment. Both of these students stated that they liked the activity and considered it fun. Ali even stated that the activity was "cognitively relaxing." When they were asked what they have learned in mathematics and biology, both responded that they learned more about photosynthesis, but they did not learn much about mathematics. During the activity, Mehmet was found to be more engaged, especially when discussing the relationships between variables. He even shared the relationship that his group found with the whole class: "When O_2 levels are constant [similar values] at 6th and 18th hours, CO2 and light intensity are inversely proportional" (Classroom Video). Even though Mehmet was not able to predict the O_2 versus light intensity graph successfully, he was actively engaged in both groups and whole class discussions. In fact, both Mehmet and Ali's graphs were incorrect predictions of the O_2 and light

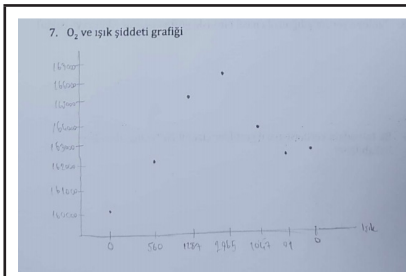	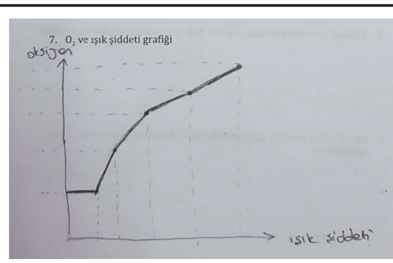	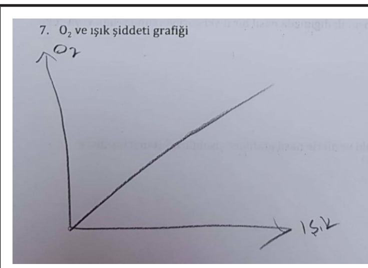
a	b	c

Figure 4. Student graphs of light intensity and O_2

intensity relationship (see Figure 5a and 5b). Ali mentioned that he was trying to draw a graph (see Figure 5a) to depict that light intensity and O_2 increase together and decrease together (Classroom Video) (Figure 5a and b). The science teacher stated that these kinds of activities were very helpful for students and he was impressed with Mehmet's engagement to the activity. He even pointed out his level of creativity and ability to express himself during the task even though he did not engage in regular classes at this level (Classroom Video).

The other students we are going to focus on are Fatma and Naz (pseudonyms) who are both considered as higher achieving female students. Even though they did not engage the whole class discussions during the activity, both of these students stated that they wanted to do more of these kinds of activities since "it was fun and educational" (Naz) and "yes, I want, since I like science, mathematics and technology" (Fatma). They were both able to see multiple relationships between variables based on the data presented in the table and their predictions of the graph of O_2 and light intensity were correct (see Figure 6a and 6b).

As seen from students' responses and worksheets, the activity based on the IMS-TEAM framework was found to be effective regardless of students' level of achievement. Average students participated more and engaged in the activity even though their understanding of science and mathematics might be weaker compared to the more successful students. But the crucial finding was that they actively participated in the activity and were motivated. The successful students, on the other hand, were able to follow the activity and answered all the questions correctly, their engagement might not have changed. Based on the video analysis regardless if they contributed to the classroom discussion or not all students appear to be fully engaged during the activity. The potential of hands-on, interactive nature of this integrated STEM activity based on the framework was able to leverage the average students' participation and might initiate their interest and motivation in the regular class environment also.

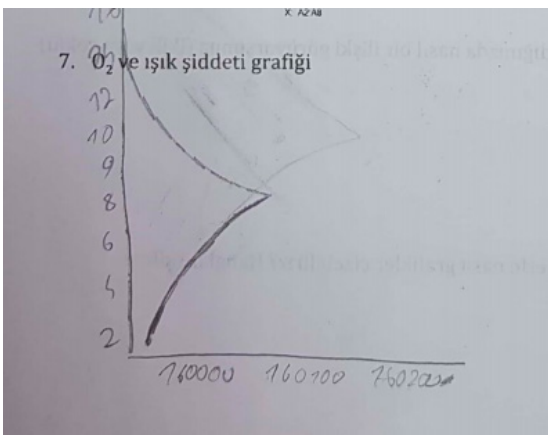

Fig. 5a: Ali's graph of O_2 and light intensity

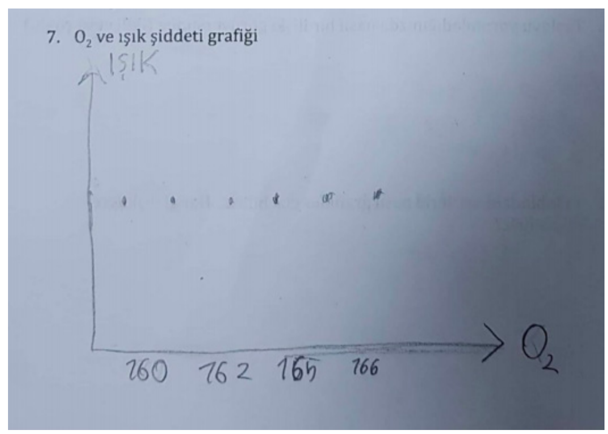

Fig. 5b: Mehmet's graph of O_2 and light intensity

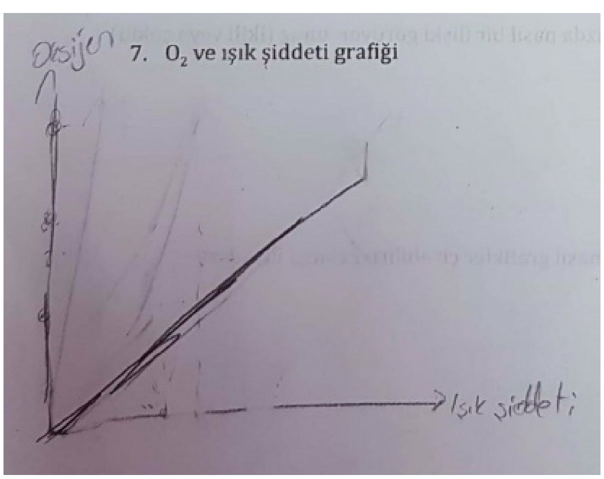

Figure 6a. Naz's graph of O_2 and light intensity

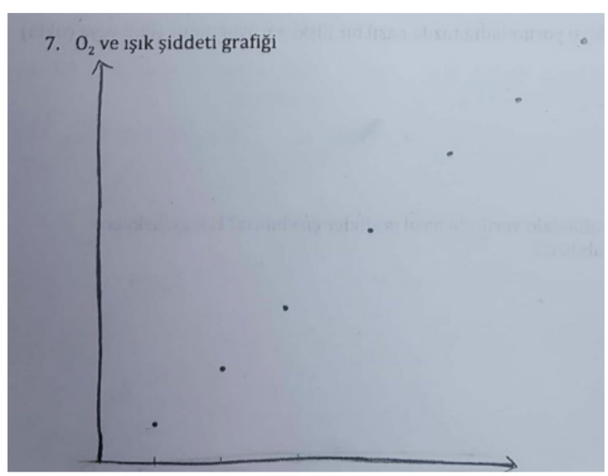

Figure 6b. Fatma's graph of O_2 and light intensity

Students' Reactions to the Activity

Students' responses to the open-ended survey about the activity were analyzed under three categories; i) their reactions to the activity, ii) what they have learned in terms of mathematics and iii) what they have learned in terms of science. Students' responses were coded and themes were identified (see Table 2).

Ninety-two percent of the students stated that they would like to do more activities like this one. The codes identified for this overwhelming positive reaction for the activity include: learning more math and science, use of technology, being fun, use of graphics/visual models, and inquiry (see Table 2). Thirty percent of the responses indicated that students learned more mathematics or science or it was an informative activity. Even though this topic was covered before the implementation of this activity, students indicated their knowledge was further enhanced and indicated they learned more. Learning with technology is identified by 26 percent of the responses as the reason to enjoy this activity: "I like being able to see the data on the digital screen." Twenty-one percent of the responses were stating that the activity was fun: "Yes I would like [to do more of these kinds of tasks]. Because it is both fun and I can easily prove myself." Inquiry was the theme stated by 11% of the responses: "I liked the part that I tried to increase the temperature value on the screen. Because we determined what to do to increase the value by thinking about it." Modeling with graphs constituted 11% of the responses. One student mentioned that he liked "analyzing the graphs, since I saw the effects [of light] on O_2 and CO_2."

At the conclusion of the lesson, students were asked if they did mathematics in this activity, many agreed verbally with this statement. In one of the classes, some of the students stated that they learned both science and mathematics and one of the students listed the concepts as "linear equation, slope, respiration…" (classroom video). When asked if the mathematics in this activity was easier or more difficult, there were mixed responses. The next question was what made mathematics easier. Students listed "visualization" "dealing with data" "interpretation" and "context" (classroom video). From these responses, we see that students appreciated the science context that mathematics was placed with visual models and technology. Students were also asked to report on what they have learned at the end of the activity in terms of mathematics via the open-ended questions. Two themes were found in this category; graphs and linear relationships. Among all responses 7 statements were on the linear relationships and slope while 14 students mentioned that they learned more about graphs. Fifteen students reported that they have not learned any new mathematics from this activity. Students were also asked to report on what they have learned at the end of the activity in terms of science. There were two categories identified from students' responses. Twenty-two students stated that photosynthesis is the topic they have learned and 9 students referred to respiration as the new content learned from the activity. Four students stated that they have not learned any new science content.

One somewhat contradictory result about the finding about the content learned came from the teacher interview. The teacher stated that in a class discussion after the activity, students reported that they found the activity more mathematics focused. This may be due to how mathematics and science curricula are structured. Having the activity in the science class might have affected students' and the teacher's perception on the matter. As stated by the teacher himself, the current science curriculum is moving away from mathematics towards a more verbal structure: "The previous science curriculum included mathematical calculations, formulas, and some graphs. However, as a result of recent changes, current content is centered around verbal interpretation instead of calculations and formulas." But the science teacher also states the benefits of using graphs, data and formulas for students to comprehend and interpret the scientific relationships and science content: "Interpretation...everything moves towards that direction...being able to see the relationships either graphically or conceptually, to express them verbally, to make connections, and interpret them...we cannot separate science

Table 2: Codes for Student Reactions

Codes	*Percentage*	*Description*
Learning more math and science	30%	Students indicating whether they learned more math, or they learned more science or both
Use of technology	26%	Students liking the use of technology for different reasons such as providing access to the different models
Being fun	21%	Students finding the activity fun and enjoying the activity
Use of graphics/visual models	11%	Students indicating the importance of visual models
Inquiry	11%	Student liking the manipulating and exploring data

and mathematics" (Teacher Interview). He even encourages his students to do mathematical calculations to check their interpretations in science class even though the curriculum does not ask for it (Teacher Interview).

Discussion & Conclusion

The goal of the IMS-TEAM framework was to integrate mathematics and science in a balanced manner in consideration of both mathematics and science curricula. English (2016) and Shaughnessy (2013) emphasized the need to leverage mathematics in STEM activities. Our results indicated that students and the teacher thought that this activity targeted both mathematics and science; it might even have highlighted more mathematics according to some students. While mathematics allowed students to study photosynthesis based on authentic data, science provided a context for abstract mathematics concepts. This was what we envisioned with the two cyclical arrows in the framework at its center (see Figure 1). The balance of integration might depend on the educators' goals and aims and there is not a fixed framework that can fit in all classrooms and curricula (Bybee, 2013). In their study, Ring-Whalen, Dare, Roehrig, Titu, & Crotty, (2018), for instance, highlighted the balance between science and engineering while mathematics was used to support this integration. The IMS-TEAM framework followed Huntley's (1998) suggestion of true integration of mathematics and science where no disciplines were used for the sake of others and supported each other.

The STEM integration activity in this study utilized technology in multiple ways. First of all, the data was collected via the sensor technology and this allowed students to work with real data. Secondly, the interactive dynamic graphing technology allowed these data to come alive with multiple representations such as visual, tabular, and algebraic models. The IMS-TEAM framework's outer ring includes technology and modeling as practices to support the teaching and learning of science and mathematics. Similar to Kelley and Knowles' (2016) framework, our IMS-TEAM framework is structured in a non-linear fashion. While mathematics and science are both at the center to leverage each other; this integration is supported with technology, modeling, authentic context, and engineering when these apply. We mentioned above that the integration should be done in a balanced manner; so that the learning outcomes for each discipline include higher order thinking skills (not just arithmetical computations for math, for instance) and important concepts. In our activity, the science and mathematics integration allowed a context for mathematics through science which led to meaningful learning and real-life connections. Similarly, mathematics provided tools and models to interpret biology.

During the whole duration of the activity, students worked as a group and carried out discussions which are aligned with other STEM frameworks (Kelley & Knowles, 2016; Thibaut et al., 2018; Walker, Moore, Guzey, & Sorge, 2018). Even though the IMS-TEAM framework did not include collaborative or team work as one of the outer-ring practices, we agree that cooperative work made the activity more effective and students learned from each other.

In a given day we have to make hundreds of real-life decisions; some on choosing the safest cleaning supplies for home or medical decisions. All these decisions, how small or big, require making connections between science, mathematics, history, or other disciplines. This way of thinking however in many cases is excluded from our ways of teaching. We tend to compartmentalize contents and even within one content, we see the same approach of compartmentalization into units, even into lessons. Through the activity based on the IMS-TEAM framework, it was possible to provide students with a learning environment where they can utilize critical thinking and problem solving to identify relationships based on real data. The use of different models afforded different ways of presentation. It is crucial for students to see that there is no one way to look at any given situation. Moreover, different models foster different learning styles as well.

This was a one-time implementation with a limited time frame (2 class hours). Future studies with more implementation hours may consider measuring the effect of the framework. Students' content knowledge achievement was not a main focus during this study due to the time restrictions of the implementation. We relied on the teacher's judgment to evaluate students' prior academic achievement. During the study classroom videos and student worksheets provide limited data on student learning. Further studies should also take into consideration effects on students' content knowledge with more deliberate measures. Students were provided with already collected 21-hour data to speed up the process; however, giving students the opportunity, if time allows, to come up with their own problem, design their own experiment and to collect data would provide them with more ownership and motivation. Moreover, the dynamic interactive graphing software was presented on the board. It would be better if each of the student groups had access to the software to create and explore different graphs by themselves. Science (e.g., photosynthesis in our case) provided a context for this activity which is part of the IMS-TEAM framework. However, if students come up with the questions and design of their experiment, the experience would be more authentic scientifically.

As Thibaut et al. (2018) stated the real-world problems are not fragmented. However, the current structure of current curricula still follows the compartmentalized approach. This compartmentalization is reflected in the teaching and learning in classrooms; hence the development of 21st century skills of students. Knowing the necessity and direction of change to integrated STEM education may not be enough to maintain a balanced integrated STEM curriculum. Different frameworks are required to be adapted to different environments with the consideration of learners and teachers. This framework can easily be extended to develop programs for teacher professional development.

Although the primary goal of the activity was the integration of mathematics and biology content using the IMS-TEAM framework and primarily technology was utilized in the process. It can very easily be adapted to include the engineering design aspect in the activity. We believe that the IMS-TEAM framework might be adapted to integrate different content or disciplines.

Limitations and Future Research

Implementation of the IMS-TEAM framework to the middle school mathematics and science curricula was limited in multiple ways. We were able to implement this with two classrooms in a limited time. Time allocated to the whole activity was 80 minutes (2 class times). Therefore, the framework was used selectively focusing on mathematics and biology content with the help of technology rather than using all of the components of the framework. Repeating this study for different content and disciplines (other than biology) with different age groups for longer time periods would allow us to use all components of the IMS-TEAM framework and inform us more about the affordances and limitations of the IMS-TEAM framework.

There were two important outcomes of this study validating future research using the IMS-TEAM framework. First of all, students who are considered average and not participating in lessons regularly (identified by the teacher) were active during the implementation process, participated in and showed critical thinking skills in their responses. Secondly, some students stated that they did not do mathematics during this lesson. They were differentiating "classroom mathematics" they regularly do and the mathematics of the activity in this task in their statements. Using an IMS-TEAM framework took learning to a different state than students used to perceive which has been very compartmentalized without the real-world connection in terms of subject matter teaching. Therefore, repeating this study with different groups of students for different content would contribute to the field in these regards.

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Statement and Declarations

All necessary permissions were obtained prior to the study. This study was approved by the Hacettepe University ethical board and all data was collected with participants' informed consent.

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