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THE USE OF TECHNOLOGY TO INTEGRATE BIOLOGY AND MATHEMATICS

Review article

Correspondence
Duygu Sönmez https://orcid.org/0000-0001-7821-6344
dsonmez@hacettepe.edu.tr
Hacettepe University, Turkey

S. Asli Özgün-Koca https://orcid.org/0000-0002-5373-8020
Wayne State University, USA
aokoca@wayne.edu

Biodatas:

Duygu Sönmez is an associate professor of science education in the Department of Science Education of Faculty of Education at Hacettepe University, Turkey. Her research interests focus on biology education, science education, climate change education, teacher professional development, STEM education and educational technology.

S. Asli Özgün-Koca is a professor of mathematics education and teaches methods, mathematics, and graduate courses in mathematics education. Her research interests are in the use of technology to enhance middle/high school mathematics education and mathematics teacher education.

THE USE OF TECHNOLOGY TO INTEGRATE BIOLOGY AND MATHEMATICS

Duygu Sönmez

dsonmez@hacettepe.edu.tr

S. Asli Özgün-Koca

aokoca@wayne.edu

Abstract

STEM education, pivotal for 21st-century skills development, requires effective integration of its disciplines, wherein purposeful technology use is essential. This paper explores the roles of technology in integrating biology and mathematics, utilizing Goos et al.'s (2000, 2003) conceptual framework, which categorizes technology as master, servant, partner, and extension-of-self. The study emphasizes the roles of technology as a servant and a partner, presenting various technologies, both hardware and software, that facilitate this integration. It provides examples from two lessons designed for middle school students and preservice science teachers. These examples illustrate the practical application of technology in educational settings, demonstrating how it functions as a servant to perform tasks efficiently and as a partner to enhance and support learning. The paper discusses the design and implementation of these lessons, highlighting the educational benefits and potential challenges of integrating technology into STEM curricula. Through these case studies, the paper underscores the importance of strategic technology use in creating interdisciplinary STEM lessons that foster deeper student understanding and engagement.

Keywords: STEM Education, Biology Education, Mathematics Education, Integrated STEM lessons, The use of technology

1. STEM Education

STEM education has been under the spotlight of the education community especially for the last couple decades with its globally accepted importance of promoting interest in STEM related careers in today’s competitive world. STEM education is truly valuable as it promotes 21st century skills including problem solving, critical thinking, creativity and collaboration among students as these skills are considered to be lacking in the workforce (Fallon et al., 2020). Despite variations in STEM integration practices among educators, the integrated STEM approach is consistently associated with enhanced student achievement. Research examining the correlation between different forms of STEM integration and student outcomes indicates that the integration of science, technology, engineering, and mathematics yields the highest effect size (Becker & Park, 2011). This comprehensive integration fosters a more cohesive understanding of these interrelated disciplines, allowing students to apply knowledge in a more interconnected and practical manner. When technology is seamlessly incorporated into STEM lessons, it serves as a powerful tool to facilitate students' learning and engagement.

The main premise of STEM education has been the economical benefits as it is expected to promote an interest in STEM careers and benefit the workforce and businesses. However, Ortiz-Revilla et al. (2020) argues on how integrated STEM education should be from an epistemological point of view and propose a “humanistic approach” that promotes content knowledge, know-how and competencies for daily life. According to their framework there are four pillars to STEM literacy which are (i) knowledge, (ii) awareness, (iii) endeavor and

(iv) engagement. Each STEM discipline serves as an entry point for one of these pillars and technology is the means of access for understanding STEM endeavors.

We believe the framework of a true integrated STEM education utilizes science and mathematics disciplines as two main pillars and technology serves as an environment and a platform. Using real-world phenomena and problems in this context allows students to have a deeper understanding. In traditional approach technology is considered a supplement in teaching strengthening the communication of messages in addition to other instructional practices in the classroom. Traditional approaches might use technology as an additional tool without a true integration, however such use of technology overlooks its potential in enhancing students' thinking skills for a specific content. Instructors should take into account various forms of technology use such as action technologies to achieve its maximum potential (Appova et al, 2023). Mathematical action technologies, for instance, are defined as technologies changing/transforming the access to, and engagement with, a task by allowing students to act on mathematical objects with autonomy, and to create meanings for themselves (Dick & Hollebrands, 2011). Since current trends of technology use in the classroom focuses on higher order thinking skills, problem solving and reasoning, we, as educators, need to take advantage of these kinds of technologies to support students' 21st century skills.

This paper presents a utilization of technology integration through integrated STEM lessons on photosynthesis using data collection sensor technology and GeoGebra and CODAP software.

1.1. Integrated STEM education

Teaching content knowledge in a compartmentalized manner has been the general approach to teaching which leads to a fragmented understanding among students. Integrated STEM education provides learning opportunities where disciplines are less fragmented and since it requires "knowledge and practices" from different STEM disciplines to solve interdisciplinary problems, connections are more evident for the learner. However, integrated STEM education is a challenge as the education system relies on a fragmented and compartmentalized approach to the disciplines (Nadelson and Seifert, 2017). Since in the real world, the problems and experiences are not fragmented (Czerniak et al., 1999) and require a systematic understanding it is important to provide students with integrated STEM experiences as a part of their learning.

STEM education is highly valued since it allows us to make connections between the disciplines of science, technology, engineering and mathematics with its interdisciplinary and /or transdisciplinary nature. Takeuchi et al, (2020) identifies transdisciplinarity of STEM as an "act of liberating disciplinary boundaries" (p.218). However, how STEM is interpreted and which approach is used by educators vary and affect its outcomes. Focusing on a single discipline-oriented approach has been a common practice which takes STEM disciplines in an isolated manner such as Biology or Mathematics (Breiner, Harkness, Johnson, & Koehler, 2012). This single discipline approach, which mostly focuses on science disciplines (English, 2016), has its shortcoming as it excludes technology and engineering disciplines of STEM education or includes them in a very limited manner (Bybee, 2010; Kelley & Knowles, 2016). In a multidisciplinary approach, disciplines are taught separately but a common theme is used; while an interdisciplinary approach uses an overlapping understanding of disciplines through a continuum. Transdisciplinary level of integration uses real-world problems to support the connections between disciplines (Vazques et al., 2013). Through these four levels (single, multi-disciplinary, interdisciplinary and transdisciplinary) we observe integration of STEM disciplines moving from a linear approach (Bybee, 2013; Huntley, 1998) towards a complex natured system such as defined by Kelley and Knowles (2016) through "situated" STEM learning. In their model they define an integrated system where scientific inquiry, mathematical thinking, technological literacy and engineering design work in synergy although integration of all four disciplines is not a must (Kelley & Knowles, 2016). Sanders (2009) emphasizes integration of "two or more STEM subject areas" or "one STEM subject area with one or more school subjects" and proposes combining scientific inquiry and technological design as well as social studies and arts. His proposal takes down the walls between technology education, science education and mathematics education. Technological literacy is also discussed by Kelley and Knowles (2016) especially from humanities perspective and they suggest educators to focus on how technology affects every aspect of our lives, such as society, environment and politics in their teaching and learning practices.

Effective integration of STEM disciplines requires a strategic and intentional approach and careful planning. The effectiveness of STEM education relies on several factors in addition to the level of integration explained above. A learning environment with access to necessary materials/technologies and a certain level of teacher knowledge are required for a successful integration (Thibaut et al., 2018). Teachers' lack of understanding of technology in STEM education as well as how it can be integrated with nature of science has been reported as a limitation for a successful STEM integration (El-Deghaidy and Mansour, 2015).

Watanabe and Huntley (1998) focusing on the mathematics and science reports that integration of these two disciplines allow students to understand the scientific relationships through mathematics and Williams (2007) states that contextual teaching allows students to see the relevancy between the mathematics they learn and their lives. In true integration of mathematics and science, science provides a context for mathematical argumentation and mathematics provides an important tool to interpret and understand science. In terms of science and mathematics integration one of the problems is the limited and effective use of mathematics to make sense of science concepts. This limited integration of mathematics to STEM lessons/tasks was also noticed by other researchers such as English (2016) and Shaughnessy (2013). In general, the integration of mathematics in STEM tasks could have been limited to the four arithmetic operations which hinders deeper understanding of both science and mathematics. For this reason, we need to implement mathematics beyond four arithmetic operations and center both science and mathematics concepts at the heart of the lessons. Finally, it's also reported that students benefit from integrated STEM education since it increases motivation and interest in STEM related content (Koul et al., 2017), engagement in learning environment (Struyf, 2019) as well as student achievement (Hurley, 2001).

1.2. The Role of Technology in STEM Integration

There are many frameworks on technology integration for effective mathematics (McCulloch et. al, 2021) and STEM education. Goos and colleagues introduced technology as Master, Servant, Partner, and Extension-of-self model back in 2000. Their categories help educators as they design instructional sequences using technology and how to scaffold student thinking with technology. Moreover, these categories are beneficial as researchers analyze the technology used by students. In this paper, we used this model to share our reasoning for the instructional decisions that we made for STEM integration.

Goos and colleagues (2000, 2003) describe how teacher and student roles could be redefined with the use of technology while categorizing different uses of technology.

> If the student uses the technology as a master, the student is dependent on the technology blindly and could not question the technology and its results. The technology is being used in a limited way.

> If the student uses technology as a servant, the student offloads cumbersome calculations and computations to the technology. Technology allows the student to save time, check the work, and be somewhat in control questioning the reasonableness of some of the feedback.
>
> If the student uses the technology as a partner, the student and the technology are at the same level completing the tasks could be impossible without technology and there is more interaction between the student and the technology with a genuine rapport between them. Furthermore, it creates more opportunities for peer and whole class discussions.
>
> If the student uses the technology as an extension-of-self, the student and the technology become one and they act together when working on a problem and create mathematical argumentation.

In the next section we will share our interpretation of Goos and colleagues' model for biology and mathematics integration, especially for the uses of technology as a servant and technology as a partner.

2. Using Multiple Technologies to Integrate Biology and Mathematics

As we mentioned above, students' STEM learning could be enhanced with integrated STEM activities. An integrated task or activity could ask students to study a biological phenomenon with data and to use mathematics in order to make sense of a biology concept. In this integration, technology could play a crucial role to support students' biological and mathematical learning as well as cognitive processes such as critical thinking and problem solving.

Using Goos and colleagues' (2000, 2003) model, in Table 1, we share how different technologies could provide various opportunities to integrate biology and mathematics. First of all, there are hardware and software technologies to support students' biological and mathematical learning. Using sensor technology, data collection for a biology experiment could be done easily. In this case, technology acts as a **servant** by collecting data and it also organizes data within a spreadsheet. The student definitely decides on the data collection setting and what data to collect at what time periods. With this kind of technology use, students' biological knowledge is more active as the main decision maker while setting up the physical experiment and deciding what data to collect to study a specific biology concept or a problem. While their mathematical learning and knowledge is more passive for this kind of use, students still could look at the data table to make sense of the biological relationships. Most of the sensor technologies produce txt or csv data files which can be very difficult to manipulate depending on what software the student opens the files.

There are different technologies for data analysis and interpretation. Some of the software could be more mathematics centric such as GeoGebra, while others are more general dynamic data analysis software such as CODAP. These technologies could be categorized as mathematics action technologies allowing students to manipulate different representations and complete complex computations which could be cumbersome to do by hand. In this role, technology acts as a **partner** by providing an environment for students to interact with multiple mathematical representations to study a biology concept. Students are in charge of organizing the table to make sense of the data. They can choose to put specific columns next to each other in order to be able to detect a potential relationship. Students can also graph specific data to see potential trends and relationships in a visual way. They can also compute various complex calculations (such as regression analyses) and use different functions to study the biology concept with multiple representations. In this example technology, as a **partner**, provides immediate feedback to students' actions and creates an environment for students to find answers to "what if" questions in a timely manner. Here both biological and mathematical knowledge building are active and they support each other.

These roles of technology can differ as a result of enactment of the lesson. A teacher might aim to use technology as a partner, but if the students use the technology blindly without questioning its results and feedback, the technology role might be decreased to a servant or even a master. Moreover, the task also needs to support the role of technology at the aimed level. On the other hand, the technology role could be increased to an extension-of-self (even though it was designed as a partner) when it is used regularly and a freedom is given students to use the technology creatively. Students need to interact with technology freely to become one.

Table 1. *Technology integration*

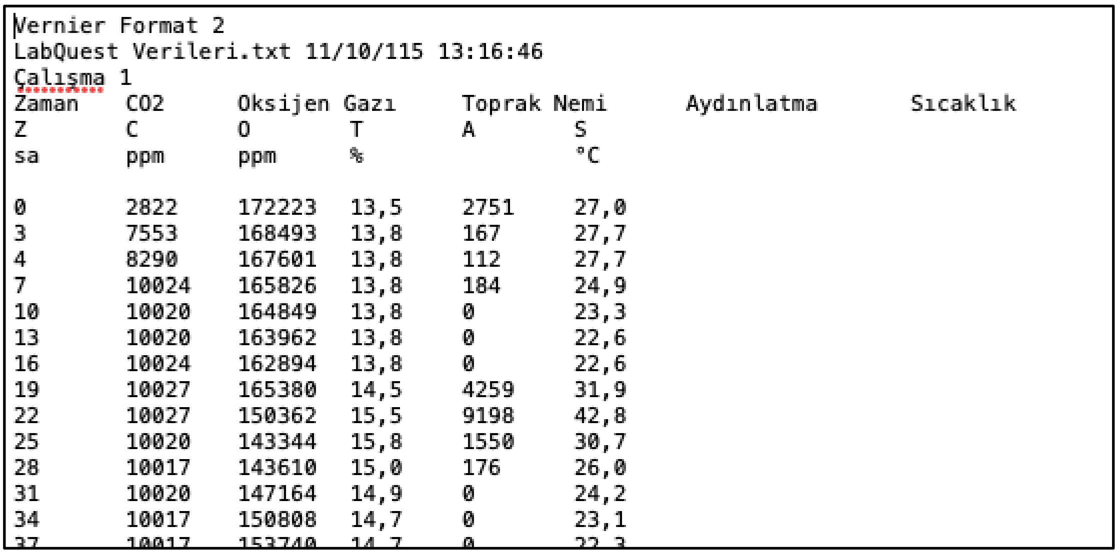
Technology Integration	Roles	Biology Education	Mathematics Education
Data collection	Technology acts as **servant** by collecting data and organizing it as a table.	Active; Setting up experiment Collecting data with various parameters	Passive; Data results are obtained via spreadsheet
	Students **decide on** ● which data variables to collect ● at what time period ● data collection setting		
Data analysis and interpretation	Technology acts as **partner** by providing immediate feedback for students actions and creates collaborative discussion opportunities	Active; 1. Interpretation of data within the biology context 2. Visualization of trends in data based on graphs 3. Identifying relationships between different biological concepts	Active; 1.Manipulation of data within tables 2.Graphing 3.Multiple linked representations (relating data within tables and graphs) 4.Regression analysis (identifying relationships and patterns between different variables)
	Students **make a decision** on ● how to construct and organize the table ● graph ● analyze and interpret data ● make conjectures in result of what if questions		

3. How Technology Can Be Integrated? Photosynthesis Example

In this section, we will provide examples of two lessons using different technologies to integrate biology and mathematics. We will analyze the role of technology using Goos and colleagues' model focusing on two roles: technology as a **servant** and technology as a **partner**. Both of the lessons presented here are designed for a specific targeted audience using STEM framework with emphasis given to technology integration. One of the lessons was designed for and enacted with middle school students using GeoGebra. The lesson plan was for two hours. The other lesson was actually unit designed for and enacted with college students (preservice science teachers) using CODAP which lasted for several weeks including the ecological design component. Both lessons were implemented successfully achieving appropriate student learning outcomes. More details regarding the technology integration to these lessons are provided below.

3.1. Technology as a servant

A closed environment to collect photosynthesis data was set up by the instructor for the middle school students. Using Vernier LabQuest with sensors, data was collected every 3 hours for Soil Humidity, Light Intensity, Oxygen, Carbon Dioxide, and Time. Figure 1 demonstrates an image of a data file in txt format. As one can see, some of the headings and data do not align and this format does not allow students to manipulate the data to look for trends. That is why, we decided not to share this file nor the data in this format with the middle school students. However, in order to make students familiar with the sensor technology and teach them how to use the technology, we brought an example of the data collection sensor (temperature probe and LabQuest) to the class and explained how we collected data. Due to time constraints, it was not possible to do long term data collection in the classroom but it was also important for students to experience how to collect data. Therefore, we asked students to obtain the highest temperature possible using the temperature sensor with a method of their choice. Some students rubbed their hands together, others blew into their hands or placed the sensor under their arms and covered them with clothing to obtain the highest temperature. The temperatures that students achieved, choice of method to achieve the highest temperature and reasons for the outcome were discussed. This inquiry introduction activity allowed students to get familiar with the LabQuest and sensor technology. In this way, technology is not a black box for students and they have a sense of how this technology works and can be used in biology context when conducting experiments. Followed by this short activity students were also introduced to a photosynthesis experiment set up which included oxygen and carbon dioxide probes. This set up created a context for students prior to the actual data presentation.

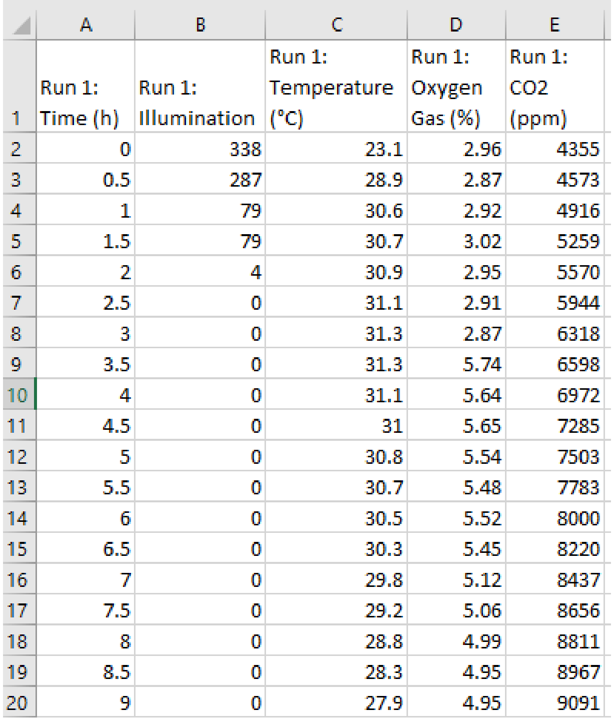


```
Vernier Format 2
LabQuest Verileri.txt 11/10/115 13:16:46
Çalışma 1
Zaman    CO2      Oksijen Gazı     Toprak Nemi      Aydınlatma       Sıcaklık
Z        C       O        T        A        S
sa       ppm     ppm      %                 °C

0        2822    172223   13,5     2751     27,0
3        7553    168493   13,8     167      27,7
4        8290    167601   13,8     112      27,7
7        10024   165826   13,8     184      24,9
10       10020   164849   13,8     0        23,3
13       10020   163962   13,8     0        22,6
16       10024   162894   13,8     0        22,6
19       10027   165380   14,5     4259     31,9
22       10027   150362   15,5     9198     42,8
25       10020   143344   15,8     1550     30,7
28       10017   143610   15,0     176      26,0
31       10020   147164   14,9     0        24,2
34       10017   150808   14,7     0        23,1
37       10017   153740   14,7     0        22,3
```

Figure 1. Data file example in txt format

In the college students' case, the data collection environment was set up together with the instructor and students aligned with the ecology content. Students were familiar with the LabQuest and sensor technology. Students decided how to set up the ecological environment and what data to collect. Data was collected every 30 minutes for Light Intensity, Temperature, Oxygen, Carbon Dioxide, and Time (see Figure 2). Data in csv format is organized better in columns which could be manipulated to explore potential trends.



	A	B	C	D	E
1	Run 1: Time (h)	Run 1: Illumination	Run 1: Temperature (°C)	Run 1: Oxygen Gas (%)	Run 1: CO2 (ppm)
2	0	338	23.1	2.96	4355
3	0.5	287	28.9	2.87	4573
4	1	79	30.6	2.92	4916
5	1.5	79	30.7	3.02	5259
6	2	4	30.9	2.95	5570
7	2.5	0	31.1	2.91	5944
8	3	0	31.3	2.87	6318
9	3.5	0	31.3	5.74	6598
10	4	0	31.1	5.64	6972
11	4.5	0	31	5.65	7285
12	5	0	30.8	5.54	7503
13	5.5	0	30.7	5.48	7783
14	6	0	30.5	5.52	8000
15	6.5	0	30.3	5.45	8220
16	7	0	29.8	5.12	8437
17	7.5	0	29.2	5.06	8656
18	8	0	28.8	4.99	8811
19	8.5	0	28.3	4.95	8967
20	9	0	27.9	4.95	9091

Figure 2. Data file example in csv format

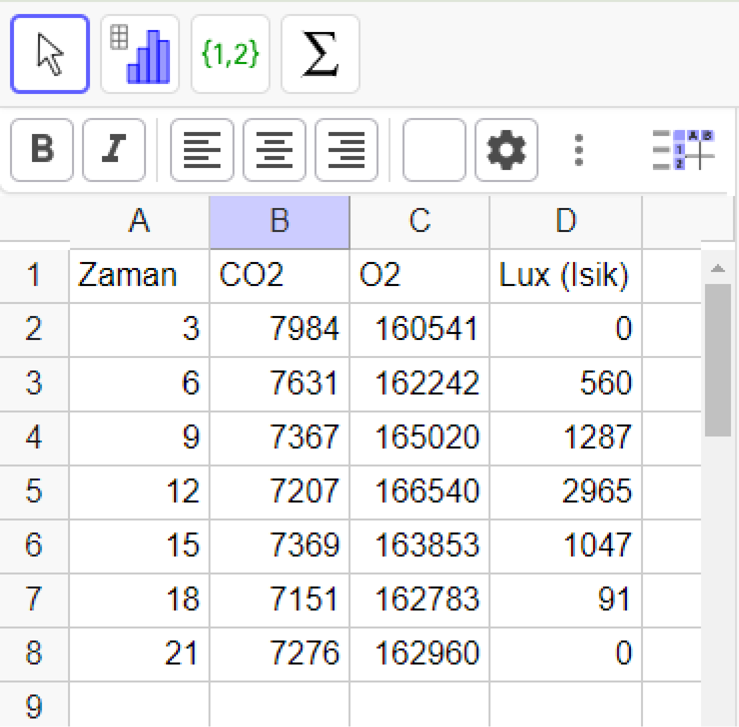
We categorize this kind of use as technology as **servant** when technology is used as data collector and organizer. Instead of collecting and recording data by hand, data is collected in a timely manner all day and night long automatically for more than 24 hours and is recorded and organized in a table. In this role, technology follows the instructions of the user and all main decisions are made by the user. Technology's main contribution is to complete cumbersome data collection and organization; however, the output (as txt and csv files) does not allow users to deep dive into the data. Having said that, collecting real-world data in an organized way for 24 hours for multiple days is a perfect example of technology as a **servant**, which is truly valuable to study various biological phenomena.

3.2. Technology as a partner

Now data is available, it can be exported to other software to study and analyze it. When analyzing the data, technology could become a collaborator providing an environment to work together. In this section, we will consider two different technologies as partners: GeoGebra and CODAP.

3.2.1. GeoGebra

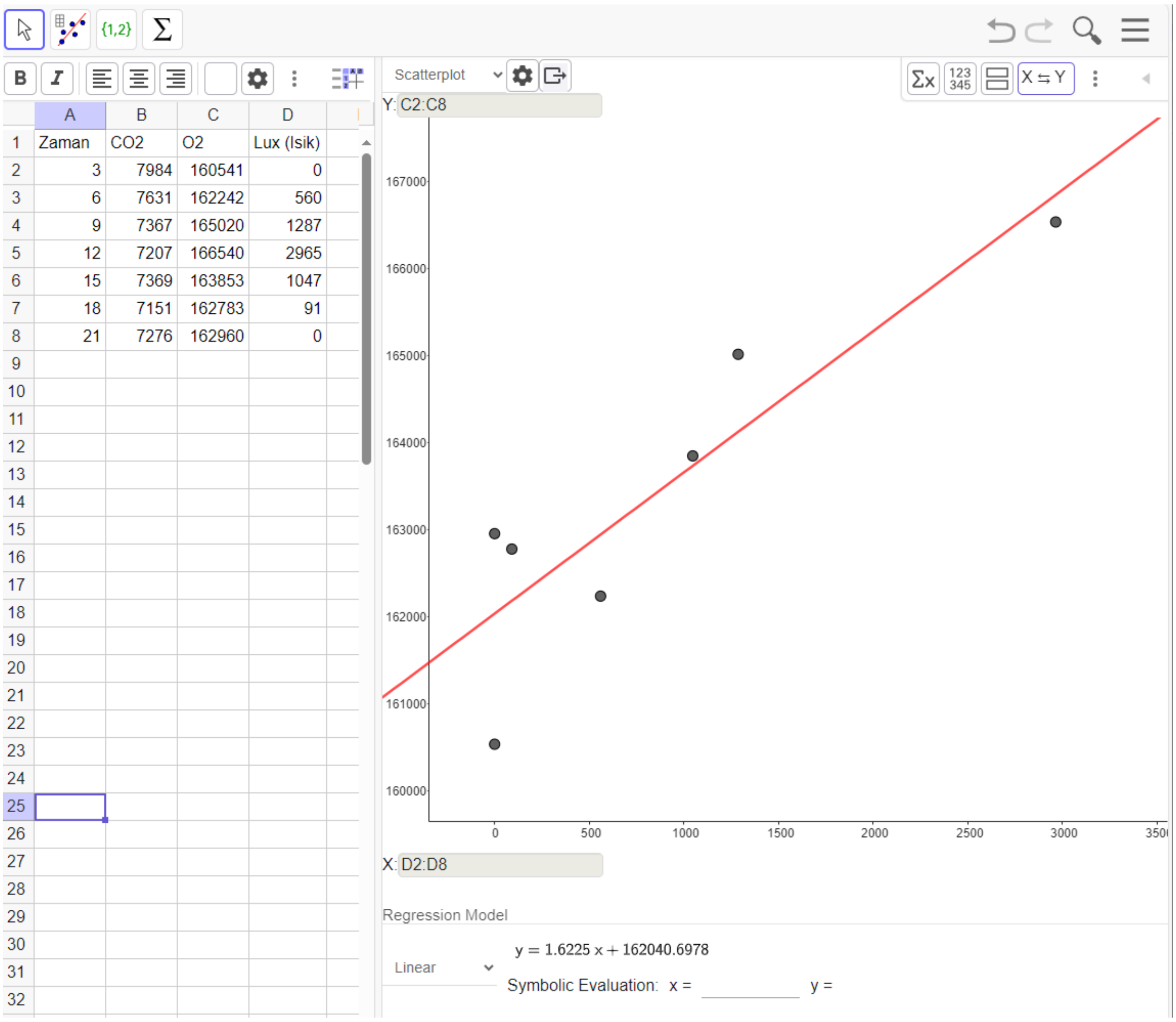
GeoGebra is a freely available online tool and "dynamic mathematics software for all levels of education that brings together geometry, algebra, spreadsheets, graphing, statistics and calculus in one engine" (https://www.geogebra.org/about). It provides multiple linked representations where other representation(s) are highlighted, updated, or changed when one representation is acted on and/or changed. We used GeoGebra with middle school students. We purposefully chose a subset of data (21 hours) for the middle school students (see Figure 3). We first looked at the data table and asked students to interpret it to identify any relationships that they observe. In this way, data was more accessible to the middle school students.



	A	B	C	D
1	Zaman	CO2	O2	Lux (Isik)
2	3	7984	160541	0
3	6	7631	162242	560
4	9	7367	165020	1287
5	12	7207	166540	2965
6	15	7369	163853	1047
7	18	7151	162783	91
8	21	7276	162960	0
9				

Figure 3. GeoGebra data table

After graphing the O_2 and Light intensity relationship, students were able to study an important concept of Photosynthesis (see Figure 4). As the light intensity increases, O_2 levels increase as well. This relationship is more accessible and visible with the graph. The positive slope and y-intercept could be interpreted for this biology concept. In order to further study this relationship mathematically, a linear regression was computed. The algebraic representation can be seen at the bottom of Figure 4. The class discussion can focus on the meanings of the 1.6225 slope and 162040 y-intercept for this data specifically and for Photosynthesis in general.



	A	B	C	D
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3	6	7631	162242	560
4	9	7367	165020	1287
5	12	7207	166540	2965
6	15	7369	163853	1047
7	18	7151	162783	91
8	21	7276	162960	0

Scatterplot

Y: C2:C8

X: D2:D8

Regression Model

Linear

y = 1.6225 x + 162040.6978

Symbolic Evaluation: x = y =

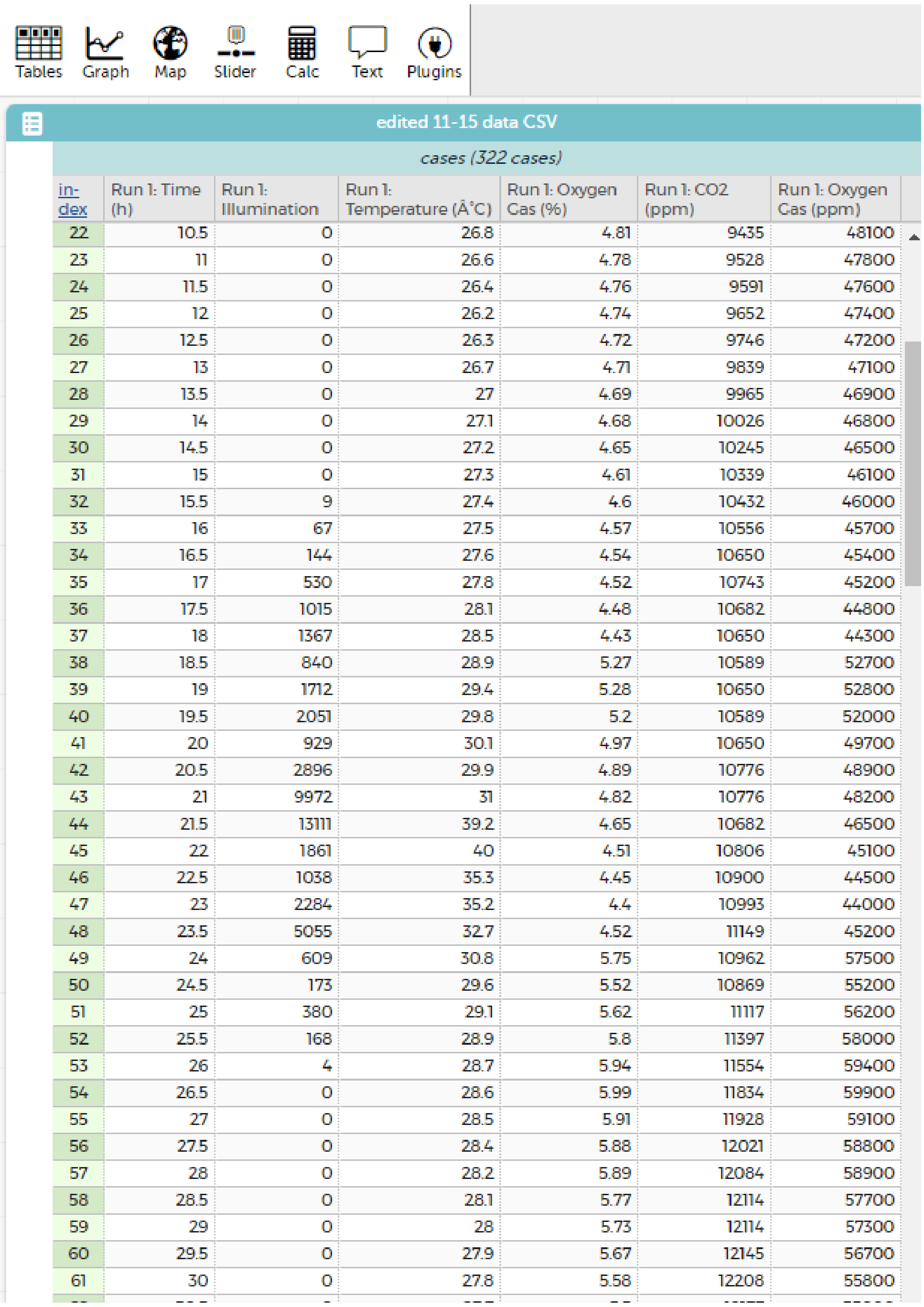
Figure 4. GeoGebra data table and graph

These discussions help students to study biology concepts with a mathematical lens. Interpretation of biological relationships with the help of mathematics would support students' both biology and mathematics learning. As opposed to the isolated teaching of science from mathematics, this lesson allows students to experience how mathematics is used in scientific processes as well as technology.

3.1.2. CODAP

Common Online Data Analysis Platform (CODAP) is “is free educational software for data analysis. This web-based data science tool is designed as a platform for developers and as an application for students in grades 6-14” (https://codap.concord.org/). CODAP is another dynamic software providing multiple linked representations.

In order for preservice teachers to get familiar with CODAP, we asked them to look at CO_2 data from NASA over the years. They were asked to look for patterns in the data table and create graphs to study any potential trends. Moreover, for the preservice teachers, we chose to share the whole photosynthesis data. CODAP comfortably can work with data with 5000 cases (see Figure 5).



edited 11-15 data CSV

cases (322 cases)

in-dex	Run 1: Time (h)	Run 1: Illumination	Run 1: Temperature (Â°C)	Run 1: Oxygen Gas (%)	Run 1: CO2 (ppm)	Run 1: Oxygen Gas (ppm)
22	10.5	0	26.8	4.81	9435	48100
23	11	0	26.6	4.78	9528	47800
24	11.5	0	26.4	4.76	9591	47600
25	12	0	26.2	4.74	9652	47400
26	12.5	0	26.3	4.72	9746	47200
27	13	0	26.7	4.71	9839	47100
28	13.5	0	27	4.69	9965	46900
29	14	0	27.1	4.68	10026	46800
30	14.5	0	27.2	4.65	10245	46500
31	15	0	27.3	4.61	10339	46100
32	15.5	9	27.4	4.6	10432	46000
33	16	67	27.5	4.57	10556	45700
34	16.5	144	27.6	4.54	10650	45400
35	17	530	27.8	4.52	10743	45200
36	17.5	1015	28.1	4.48	10682	44800
37	18	1367	28.5	4.43	10650	44300
38	18.5	840	28.9	5.27	10589	52700
39	19	1712	29.4	5.28	10650	52800
40	19.5	2051	29.8	5.2	10589	52000
41	20	929	30.1	4.97	10650	49700
42	20.5	2896	29.9	4.89	10776	48900
43	21	9972	31	4.82	10776	48200
44	21.5	13111	39.2	4.65	10682	46500
45	22	1861	40	4.51	10806	45100
46	22.5	1038	35.3	4.45	10900	44500
47	23	2284	35.2	4.4	10993	44000
48	23.5	5055	32.7	4.52	11149	45200
49	24	609	30.8	5.75	10962	57500
50	24.5	173	29.6	5.52	10869	55200
51	25	380	29.1	5.62	11117	56200
52	25.5	168	28.9	5.8	11397	58000
53	26	4	28.7	5.94	11554	59400
54	26.5	0	28.6	5.99	11834	59900
55	27	0	28.5	5.91	11928	59100
56	27.5	0	28.4	5.88	12021	58800
57	28	0	28.2	5.89	12084	58900
58	28.5	0	28.1	5.77	12114	57700
59	29	0	28	5.73	12114	57300
60	29.5	0	27.9	5.67	12145	56700
61	30	0	27.8	5.58	12208	55800

Figure 5. CODAP data table

We wanted preservice science teachers to look at real-world photosynthesis data with all complexities and potential irregularities. We asked them to share their observations by using notice and wonder questions (See Figure 6). Two additional specific tasks were:

- What kind of changes do you observe in different variables for specific time intervals?
- Identify three different time intervals to compare and analyze.

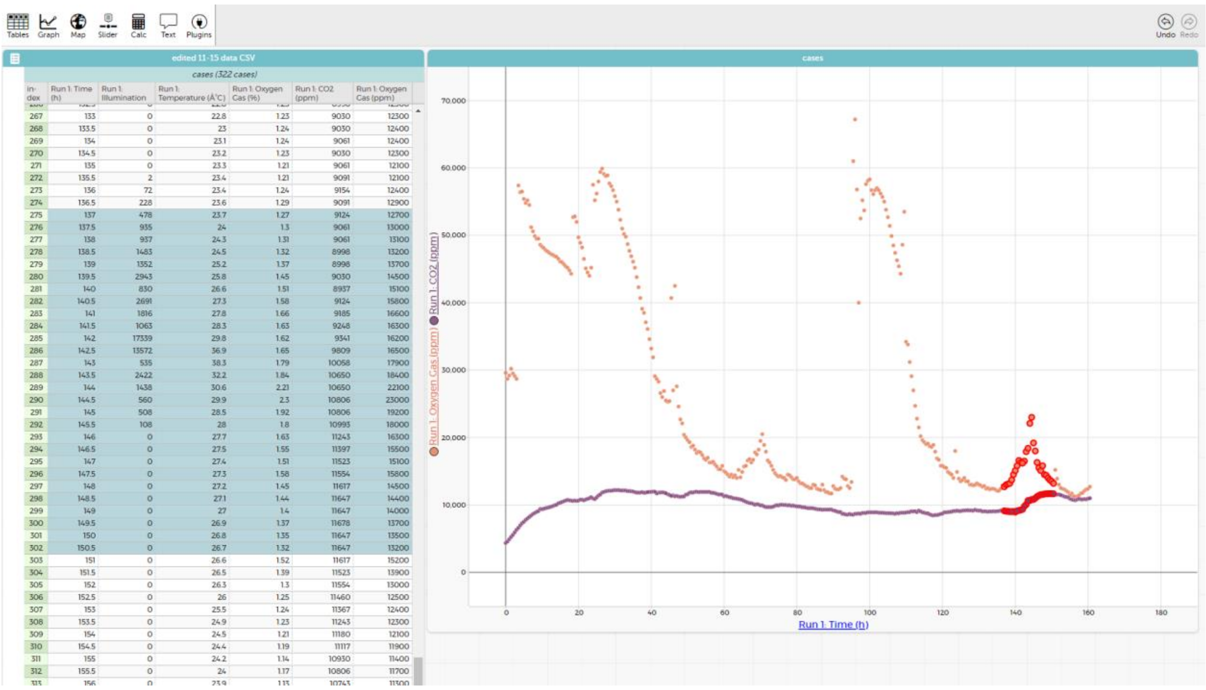
Write down what you notice and what you wonder in the table below.

What do I notice?	What do I wonder?

Using CODAP, create multiple different graphs to analyze the data

Figure 6. Notice and wonder task

During these tasks, preservice teachers worked with CODAP as partners. While students decided what to graph, technology provided immediate feedback to their actions and linked the data cases in the table and the graphs. Figure 7 demonstrates a CODAP screenshot with a data table and a graph produced with O_2 and CO_2 levels against time. Furthermore, users can choose data cases within the table or graph to see them in both representations to study specific changes and potential relationships for different time intervals (see highlighted section in both graphical and tabular representations).



edited 11-15 data CSV

cases (322 cases)

index	Run 1: Time (h)	Run 1: Illumination	Run 1: Temperature (Å°C)	Run 1: Oxygen Gas (%)	Run 1: CO2 (ppm)	Run 1: Oxygen Gas (ppm)
267	133	0	22.8	1.23	9030	12300
268	133.5	0	23	1.24	9030	12400
269	134	0	23.1	1.24	9061	12400
270	134.5	0	23.2	1.23	9030	12300
271	135	0	23.3	1.21	9061	12100
272	135.5	2	23.4	1.21	9091	12100
273	136	72	23.4	1.24	9154	12400
274	136.5	228	23.6	1.29	9091	12900
275	137	478	23.7	1.27	9124	12700
276	137.5	935	24	1.3	9061	13000
277	138	937	24.3	1.31	9061	13100
278	138.5	1483	24.5	1.32	8998	13200
279	139	1352	25.2	1.37	8998	13700
280	139.5	2943	25.8	1.45	9030	14500
281	140	830	26.6	1.51	8937	15100
282	140.5	2691	27.3	1.58	9124	15800
283	141	1816	27.8	1.66	9185	16600
284	141.5	1063	28.3	1.63	9248	16300
285	142	17339	29.8	1.62	9341	16200
286	142.5	13572	36.9	1.65	9809	16500
287	143	535	38.3	1.79	10058	17900
288	143.5	2422	32.2	1.84	10650	18400
289	144	1438	30.6	2.21	10650	22100
290	144.5	560	29.9	2.3	10806	23000
291	145	508	28.5	1.92	10806	19200
292	145.5	108	28	1.8	10993	18000
293	146	0	27.7	1.63	11243	16300
294	146.5	0	27.5	1.55	11397	15500
295	147	0	27.4	1.51	11523	15100
296	147.5	0	27.3	1.58	11554	15800
297	148	0	27.2	1.45	11617	14500
298	148.5	0	27.1	1.44	11647	14400
299	149	0	27	1.4	11647	14000
300	149.5	0	26.9	1.37	11678	13700
301	150	0	26.8	1.35	11647	13500
302	150.5	0	26.7	1.32	11647	13200
303	151	0	26.6	1.52	11617	15200
304	151.5	0	26.5	1.39	11523	13900
305	152	0	26.3	1.3	11554	13000
306	152.5	0	26	1.25	11460	12500
307	153	0	25.5	1.24	11367	12400
308	153.5	0	24.9	1.23	11243	12300
309	154	0	24.5	1.21	11180	12100
310	154.5	0	24.4	1.19	11117	11900
311	155	0	24.2	1.14	10930	11400
312	155.5	0	24	1.17	10806	11700
313	156	0	23.9	1.13	10743	11300

Figure 7. CODAP Data table and graph

3.1.3. GeoGebra and CODAP as partners

When technology is used as a **partner**, it becomes a peer to the user when completing the tasks. Technology's computational power assists the user to complete calculations that could be either impossible without technology or very cumbersome. In both GeoGebra and CODAP cases, they provide students all three tabular, graphical, and algebraic representations (if they complete regression analysis, see Figure 4 for GeoGebra example) to study and analyze. Similar to the technology as a **servant**, all main decisions are made by the user when the technology is used as a **partner**. However, technology's role is more elevated as it completes complex calculations, creating complex graphs, and linking multiple representations which could be very time consuming to do. This way it frees the user to focus on the concepts and relationships. In our case, technology was used in one lesson with middle school students and in one unit with the preservice teachers. This kind of use prevents technology becoming extension-of-self for students. For extension-of-self level, technology needs to be a permanent part of the daily classroom tasks and used regularly.

Use of technology, is not limited to the two examples we presented above. Different technologies and various integrations could be considered to facilitate STEM learning for instance; Martinovic and Manizade (2014) employs graphing technologies as a partner to deal with preservice teachers' misconceptions while focusing on geometric conjectures. In their example they emphasize the importance of designing tasks carefully and allowing students with opportunity for reflection and interpretation. Shin (2021), uses intelligent tutoring systems (ITS) and investigates preservice teachers positioning (ITS) either as a partner or a servant in lesson planning and how their positioning is related to their technological, pedagogical, and content knowledge. At secondary grade levels Leng (2011) uses graphing calculators to use calculus aiming to help students to visualize concepts taught and reports the study as a proof of using technology as a servant by the students. As seen from these examples, technology can be used at different grade levels, for different content and with roles such as servant or master. However, technology as Master, Servant, Partner, and Extension-of-self model is more accepted in mathematics education but not in science education.

4. Concluding Thoughts

The question of how STEM education should be structured remains a central inquiry within the field. Although there is no universally correct answer, the effectiveness of STEM education varies based on factors such as age group, context, learning environment, culture, and student demographics. It is crucial to consider these factors during the design phase of any STEM activity or lesson to maximize successful outcomes.

This paper examines the use of multiple technologies to integrate biology and mathematics. The software tools discussed in the examples, along with other available software, can facilitate computational use of technology for STEM education. We present two STEM lessons focused on photosynthesis that integrate technology effectively to allow students explore photosynthesis in empowering ways.

Traditionally, technology has been used merely as a supplement in educational settings, overlooking its potential to enhance critical thinking skills—skills that are emphasized as essential for the 21st century. Through the lessons detailed in this paper, we aim to provide an example for technology integration that supports the development of students' higher-order thinking skills. By identifying technology's role as either a servant or a partner, we can determine whether students will take an active or passive role in learning science and mathematics content and plan for the expected outcomes accordingly. Given that real-world problems are inherently interdisciplinary and that technology is integral to daily life, it is vital for students to understand how to utilize technology for various tasks and to gain a deeper understanding of disciplines such as science and mathematics and their interconnections.

Use of technology as Master, Servant, Partner, and Extension-of-self model has been applied more in mathematics education. There is a need for interpretation of this model for other disciplines, especially science education. The two example lessons presented in this paper illustrate the use of technology within a mathematics- and science-centered context. Considering the tendency to marginalize mathematics within science curricula, the integration of technology offers a unique opportunity to truly interweave science and mathematics. This approach not only aligns with the interdisciplinary nature of real-world problems but also enhances students' comprehensive understanding and application of STEM disciplines. Educators and researchers would benefit from understanding various integration of technology, such as servant or partner. Especially technology as Partner, and Extension-of-self would promote 21st Century Skills such including high order thinking skills and problem solving.

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