RESEARCH ON LEARNING

Ecology Lessons 2.0 – A Wireless Approach: The Impact of Using Wireless Sensors and Mobile Devices in Ecology Instruction

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Abstract

This case study examines students' perception, motivation, and learning gain of a teaching unit featuring wireless sensors as tools to collect scientific data in the classroom. Students analyze data using the corresponding cellphone app, communicate findings to the class, and learn about a changing environment. Wireless sensors are produced for technology-based science lessons and are therefore suitable for our teaching unit to implement into the secondary school curriculum in the context of ecology. We aimed for very simple experimental setups in order to put the focus on handling the modern technical equipment, to make analyzing and learning from the collected data a priority, and to reduce expenses for teachers on busy schooldays. We validated the approach in German school settings with 67 students aged between 16 and 19 years. We found that our practical approach not only leads to high learning gains combined with learning enjoyment, a feeling of competence, and little perceived pressure but also improves students' understanding of scientific data.

Key Words: *science education; ecology; data analysis; wireless sensors; inquiry-based learning.*

○ Introduction

Ecology is a data-intensive biological discipline that manages large amounts of data acquired from environmental observations and subsequently transforms it into scientific knowledge (Michener & Jones, 2012). One of the major ways to collect environmental data is by using sensors that measure changing environmental variables like carbon dioxide (CO_2) or oxygen. Hereby, it is possible to report and even model environmental processes that cannot be observed directly (Porter et al., 2009). Recently, typical sensors have technically been underlying innovative developments, even in educational contexts. Innovations range from wired sensors linked to data loggers to wireless sensor systems, which combine specific sensors to acquire data and the capacity to process and analyze them within the corresponding sensor network (Collins et al., 2006). Modern sensors automatically collect data from diverse ecological landscapes at high frequencies and over large spatial scales (Porter et al., 2009). As a consequence of this, there is no need for scientists to visit sensors in the field, which could be time-consuming, costly, or even dangerous in certain ecosystems (Porter et al., 2005).

As wireless sensor systems mark a new era in ecology as a growing and interdisciplinary science (Benson et al., 2010) that covers both environmental and social developments, it becomes increasingly important for policymakers in terms of conservation and management of natural resources (Fleishman et al., 2011). In times of climate change, when students worldwide protest on Fridays to encourage and demand attention and government action in relation to the climate crisis (Boulianne et al., 2020), it also becomes important for science education to provide the understanding and the skills for students to engage in science-related civic issues (Rudolph & Horibe, 2016). As science education should generally help students learn science content and help them to understand the creation of scientific knowledge (Rudolph, 2020), practical work in science education is regarded as essential to encourage students' participation and the development of knowledge and skills (Moore et al., 2020). Earlier studies conducted in science classes already established that both field trips to real local ecosystems and hands-on materials in school settings equally influence students' learning motivation positively and provide them consequently with high learning gains (Albedyll et al., 2017; Sieg & Dreesmann, 2022).

As part of our research and developmental project called *WinUM 2.0*, we incorporate wireless sensors as efficient and trendsetting tools used in scientific practice into ecology instruction. Generally, our research and developmental project *WinUM 2.0* focuses on innovative teaching strategies and materials to let students exploit the vineyard as an ecosystem. As vines are extremely sensitive to environmental changes, especially to changes in climate (Hannah et al., 2013), this ecosystem serves as a model to convey the effects of global climate change to the students. Using wireless sensors connected to mobile devices, real-time observations of environmental factors become possible and changes in plant physiology become measurable. To prepare students for using the wireless sensors in the vineyard and to give them insight into environmental factors in times of global climate change, we developed a set of hands-on teaching materials that incorporate wireless sensors as efficient and trendsetting tools used in scientific practice. This approach is

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especially helpful because time is limited during a field trip and the trip becomes more effective and the results become more meaningful if students are already familiar with the method and have general assumptions about the effects of environmental factors on plants. In this way, we brought "real science" to the classroom and made students familiar with modern measurement technology similar to sensors, which are used in research contexts. By letting students use the sensors as tools to acquire data from experimental setups, analyze and interpret the data, and explain and communicate their own experimental findings to the class, the important factors of inquiry-based learning can be met (Krajcik et al., 2000). Based on that we gain the perspective of implementing measurement technology in extracurricular places as well.

○ Research Questions

By means of implementing the teaching unit into the classroom, we would like to find out what students' personal perception of the technology-based practical approach is (Research question 1) and how the intervention influences students' learning gains, learning enjoyment, feeling of competence, and perceived pressure (Research question 2).

○ The Practical Approach

Structure of the Teaching Unit

The teaching unit called "Environmental Factors and Climate Change" is a part of *WinUM 2.0*, was designed for the duration of approximately four school lessons and comprises three consecutive parts (Figure 1).

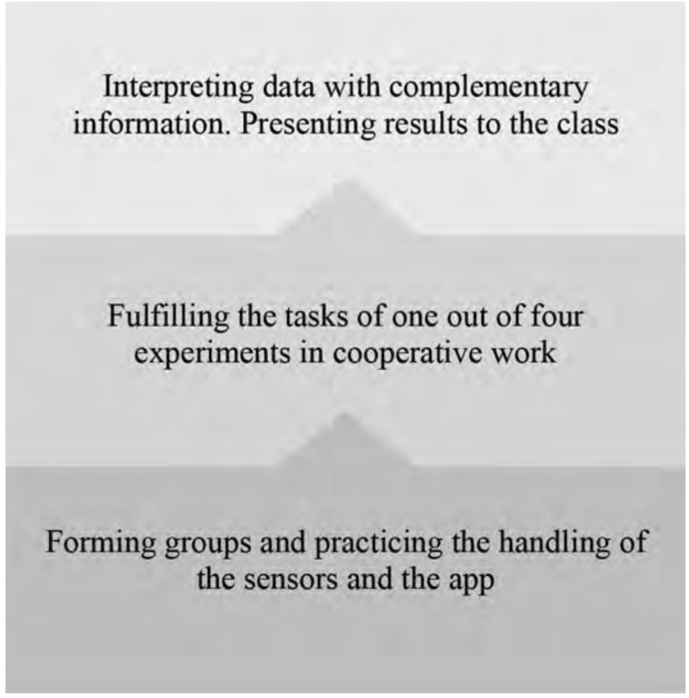


Figure 1. Structure of the teaching unit. From bottom to top: Teachers were asked to first let their students form groups of 3–4 and to provide them with the experimental tools and with instructions. Then, student groups worked independently on their respective tasks and afterward prepared their results for presentation and communicated findings to the class.

With reference to the time required, the largest part of the teaching unit is represented by the students working in small groups on one of the four experiments (Table 1) all concerning ecological contexts like the increasing CO_2 concentration in the air, acidification of the seas, or photosynthesis. To be able to engage in these major ecological issues in the classroom, representative experiments suitable for school had to be developed and enable students to measure and analyze data themselves using designated wireless sensors and the corresponding cellphone app.

To explain how students set up and carry out the experiments (Table 1), we use experiment 4 as an example (Figure 2). In experiment 4, students measure the rate of photosynthesis of green leaves in a closed system in three different setups: full light, medium light, and in the dark. To achieve full light, the green leaves are brought

Table 1. Overview of the four experiments student groups can work on using wireless sensors.

Experiment	Tasks	Type of Wireless Sensor Used
1. Quantitative CO_2 concentrations	Measuring the CO_2 concentration of fresh air, exhaled air, and indoors. Analyzing and interpreting the collected data	CO_2 sensor
2. Effects of CO_2 on the pH value of water	Measuring the pH value of carbonated water and noncarbonated water and measuring the changes in pH while inserting CO_2 into the tap water. Analyzing and interpreting the collected data	CO_2 sensor, pH sensor
3. Effects of temperature on photosynthesis	Measuring the rate of photosynthesis of green leaves in a closed system at cold temperature, medium temperature, and hot temperature. Analyzing and interpreting the collected data	CO_2 sensor, temperature sensor
4. Effects of light on photosynthesis	Measuring the rate of photosynthesis of green leaves in a closed system in full light, medium light, and in the dark. Analyzing and interpreting the collected data	CO_2 sensor, light sensor

under a light source at a distance of 20 cm. To achieve medium light, the light source is brought at a distance of 40 cm distance. For the setup in the darkness, the closed system containing the green leaves is wrapped in aluminum foil.

Our approach can equally be integrated into school settings around the globe as the environmental content discussed is equally important to students all over the world and the technical equipment we used is available in more than 100 countries and provides various language settings.

Technical Tools

In our teaching unit, we used wireless CO_2 sensors, wireless temperature sensors, wireless light sensors, and wireless pH sensors (Figure 3) to measure environmental factors in experimental setups in the classroom. We tested wireless sensor systems from different manufacturers and chose PASCO *scientific – Science Lab Equipment & Teacher Resources*, an American manufacturer that provides products for science education. We chose PASCO for reasons of handling, robustness of the equipment, and availability of the app in German. See https://www.pasco.com/p/trademarks-and-patents for further information.

Wireless sensors must necessarily be connected to a corresponding cellphone app (Figure 4) suitable for Apple and Android operating systems on Tablets and smartphones, which visualizes data in real time and allows analyzing the collected data by manipulating graphs flexibly.

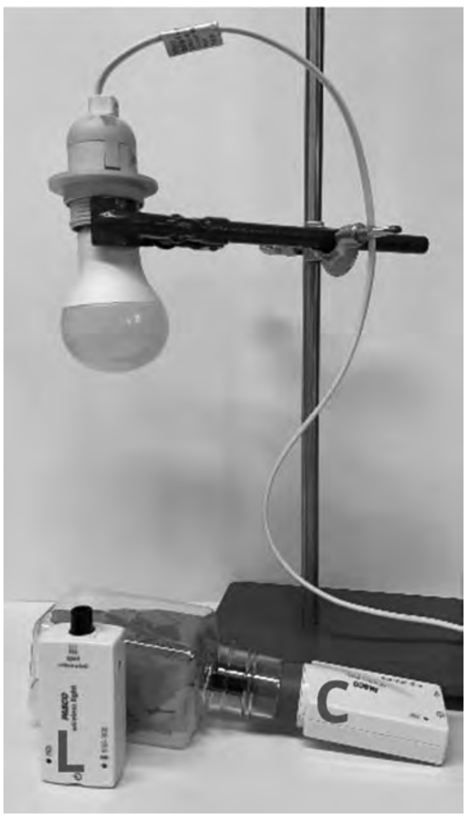


Figure 2. Overview of experiment 4: Effects of light on photosynthesis. The basic experimental setup is shown: green leaves in a closed system are brought under a light source. The CO_2 sensor (“C” in the picture) measures the CO_2 value in the closed system. Next to it, the light sensor (“L” in the picture) measures light.

Figure 3. Wireless sensors used. From top to bottom: wireless CO_2 sensor, wireless pH sensor, wireless temperature sensor, and wireless light sensor from PASCO.

To connect the sensor to the app, the user has to first switch on the sensor and then open SPARKvue on a digital device. After having started a new experiment in the app, the user has to press the Bluetooth button on the interactive surface and choose the sensor they want to connect by its sensor name on the front. Now, the user is able to press “Start” and collect data, changes in variables are simultaneously displayed in a coordinate system (see Figure 4).

By pressing “Stop,” data collection stops and the recorded graphs can be stored or manipulated in the app to serve as the basis for data interpretation.

○ Study Design and Participants

To implement our teaching unit into the classroom, we selected four learning groups that equaled a total of 67 participants. Their ages ranged from 16 to 19 (median = 17) and they were all 1–3 years away from their high school graduation, which is normally after grade 12 or 13 in Germany; 28 of the participants were male and 39 were female, respectively. All teachers implemented the teaching unit in their biology lessons in the context of ecology after having discussed the processes of photosynthesis in the preceding school lessons.

○ Evaluation Instrument

We evaluated our case study with a paper–pencil approach in a pretest–posttest design and collected qualitative as well as quantitative data before and after the teaching units.

Students’ perception was evaluated with the open-ended question: “What did you like best about the practical approach?” Additionally, actual motivation was evaluated in the pretest with the Questionnaire of Current Motivation (QCM, Rheinberg et al., 2001) to measure four motivational factors (anxiety, probability of success, interest, and challenge). Intrinsic motivation was evaluated in the posttest (Wilde et al., 2009) to test learning enjoyment, perceived competence, perceived pressure, and freedom of choice. We left out the factor “freedom of choice” as students were assigned their tasks and not given the possibility to choose between various options. The items of both tests were measured by a five-tier Likert scale ("strongly agree," "agree," "neutral," "disagree," "strongly disagree").

Learning gain was evaluated with a questionnaire consisting of five statements about environmental factors and climate change with the answer options correct/wrong/I don't know. We included the answer option "I don't know" to every statement to prevent students from pure guessing if the statement is correct or not and encourage them to tick this option instead. For the evaluation of learning gain, see Table 2.

To test understanding of scientific data and skills as a subdomain of learning gains, an additional chart template where students had to sketch in the correlation between two environmental factors without being quantitatively exact was given. Responses were rated as correct when a student assumed the right trend of the curve in the template and as wrong if they assumed a totally different or opposite trend. All items concerning learning, gain and understanding of scientific data evolve around the topic of abiotic factors, which is obligatory in the German school curriculum for biology classes and is essential for understanding plant physiology and how ecosystems function in general. Filling out the questionnaires and answering the open-ended questions were explicitly voluntary and ungraded for all students. On this basis, we aimed to achieve truthful responses that represent true knowledge and opinions.

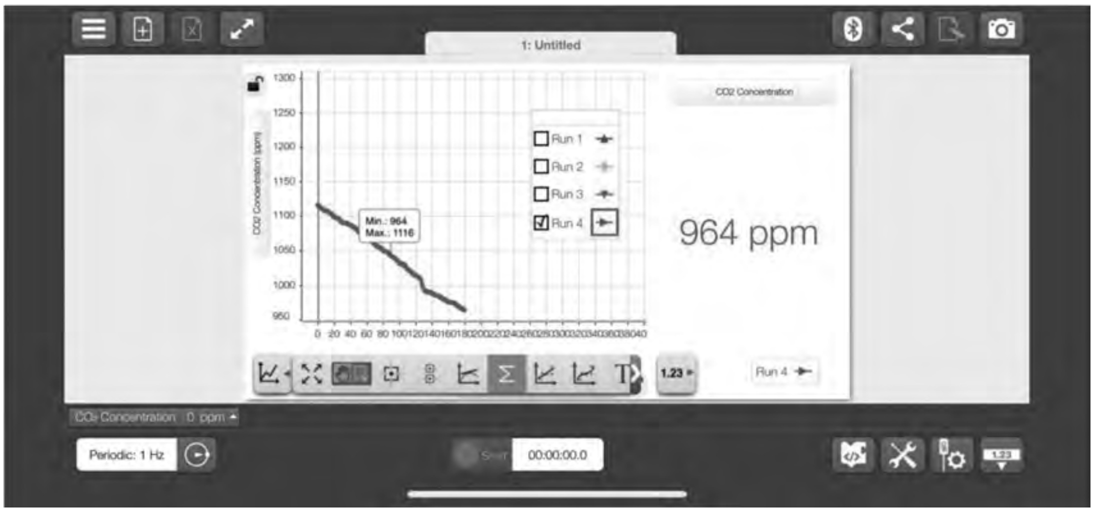
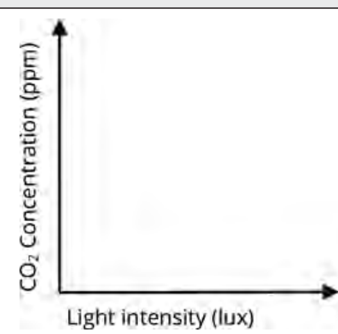


Figure 4. Interactive surface of the SPARKvue app on a cellphone. Data from measuring the CO_2 concentration in a closed system over the period of 180 seconds are shown (red curve on the left side and red number on the right side). Minimum and maximum CO_2 concentration during this time period is shown as well.

Table 2. The questionnaire for learning gain consisted of five items (1.1–1.5) and an additional task concerning understanding of scientific data (2). Items and task were translated from German by the authors.

Items	Questions	Response Alternatives
1.1	The actual concentration of CO_2 in the atmosphere is around 415 ppm.	Correct/wrong/I don't know
1.2	The rise in the earth's mean temperature is due to the rise in the CO_2 concentration in the atmosphere.	Correct/wrong/I don't know
1.3	Because of human activities environmental factors are changing and local conditions for plants are changing as a consequence.	Correct/wrong/I don't know
1.4	Climate change can exclusively be perceived through rising temperatures.	Correct/wrong/I don't know
1.5	Short-term interventions to slow down CO_2 emissions like during the Covid-19 pandemic in the year 2020 can really slow down climate change.	Correct/wrong/I don't know
2	**Imagine the following scenario: In an experiment, a plant is located in a closed system and data from this system is collected. Use the chart template to sketch in the following correlation:** The higher the light intensity the higher the CO_2 consumption.	

○ Results

Students' Perception and Motivation

After bringing our materials to four students' groups varying in type of school, grade, and age, all teachers reported a successful implementation of the teaching unit into their lessons in the predefined time frame. We evaluated students' responses to the posttest question "What did you like best about the approach" by assigning aligning responses into categories (Table 3). On that note, we created five categories after having read all the student responses. The most common category features responses about the hands-on materials (19 responses). Next, 15 students concretized that trying out and experimenting with the modern technical equipment was what they liked best.

Additionally, illustrative students' results from experiment 4 provided by one of the participating teachers indicate that experiments and measurements with the wireless sensors had been successful and that students have used the right tools to analyze their data in the corresponding app (see Figure 5).

We also evaluated quantitative data of intrinsic motivation (learning enjoyment, acquired competencies, and perceived pressure) in the posttest and rated the highest level with the value 5, whereas the lowest level corresponded to the value 1. Overall, the 67 students enjoyed the project (median = 3.7), felt competent with their activities (median = 4), and experienced little pressure during the tasks (median = 2).

Table 3. Categorized responses to the open-response question of student's perception of the practical approach ($N = 67$). The number of students who described their perception aligning with each category is given. Additional sample responses (translated from German by the authors) to the question: "What did you like best about the practical approach?" are given to each category.

Categories	Total	Sample Responses
Hands-on materials	19	• "Experimenting in general" • "The own execution"
Modern technical equipment	15	• "To have the possibility to collect data scientifically and technically correct" • "Using a decent pH meter"
Teamwork	9	• "Working in groups" • "Teamwork and community"
Content	7	• "Learning new things and dealing with very important topics (climate change)" • "That the experiments showed various factors from our everyday lives"
No response	16	-

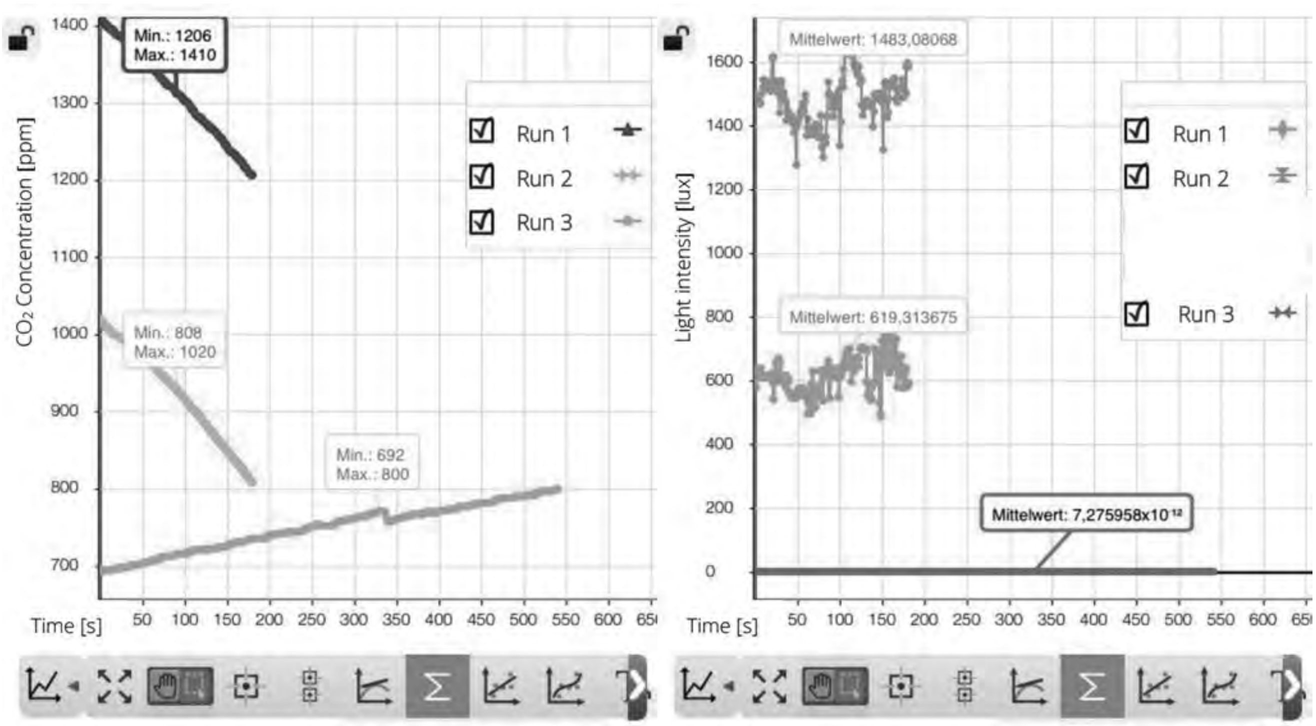


Figure 5. Screenshot from the SPARKvue app-Surface with student results from experiment 4: Effects of light on photosynthesis. Left: Recorded changes in the CO_2 concentration in a closed system with green leaves in three experimental setups (full light: Run 1, medium light: Run 2, darkness: Run 3). Right: Recorded light intensity in three setups. From the toolbar on the bottom students chose instruments to show minimum and maximum of the recorded data (left) as well as the medium ("Mittelwert") of the recorded data (right). These manipulations are important to calculate the rate of photosynthesis out of the changes in CO_2 concentration and correlate it with light intensity.

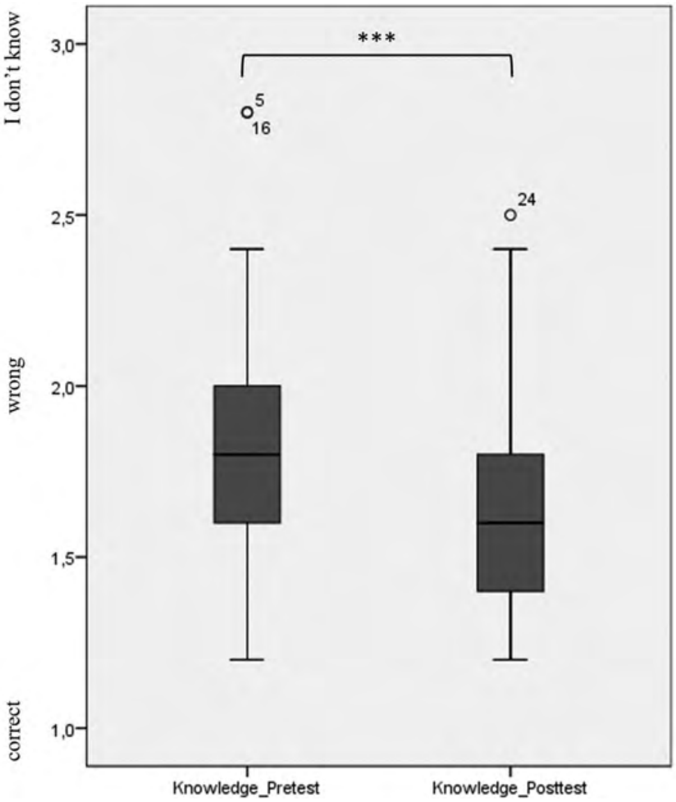


Figure 6. Pretest (left) and posttest (right) learning scores. The mean for every response option (correct, wrong, and "I don't know") is given. The number of correct answers differs significantly (***) between pretest and posttest.

Learning Gain

We evaluated the data with IBM SPSS (Version 23.0) following Field (2018) and used nonparametric tests as our data were not normally distributed. To evaluate learning gain, we rated correct answers with 1, incorrect answers with 2, and the answer "I don't know" with 3. A Wilcoxon ranks test indicated highly significant learning gains ($P < 0.001$) comparing students' knowledge about environmental factors and climate change of the pretest (median = 1.8, mean = 1.88; SD = 0.32) and the posttest (median = 1.6, mean = 1.69; SD = 0.34) (see Figure 6). The calculation of the effect size according to Cohen (1992) resulted in a small effect ($r = -0.33$). Explicitly, students with a high probability of success in the pretest (Cronbach's α: 0.69) showed significantly high learning gain, perceived themselves very competent (Cronbach's α: 0.84) showed high learning enjoyment (Cronbach's α: 0.84), and perceived little pressure (Cronbach's α: 0.84) in the posttest.

Additionally, student's understanding of scientific data was tested by the task to visualize data correlations in a chart. In the pretest, 48 students ($N = 67$) were n't able to solve the task of visualizing data correlations in a chart template correctly but 9 students did. In the posttest, the number of students who answered correctly, almost tripled up to 26, leaving 27 students who answered wrong. A Wilcoxon signed-ranks test indicated that participants' skills of visualizing data correlations in a chart template were significantly higher having collected and processed data by themselves in the teaching unit compared to before ($z = -2.41$, $P = 0.016$, $r = -0.21$). To get an insight into the improved understanding between pretest and posttest, see Figure 7.

○ Discussion

Enjoyment with Practical and New Teaching Methods

After the investigation half of the participating students responded that they appreciated practical hands-on materials and experimenting with modern technical equipment the most. Unfortunately, a lot of students bailed on the posttest (25% didn't reply to this open-ended question) and didn't make any statements regarding their perception of the teaching materials and tools or didn't fill out the entire tasks on knowledge or data analysis. This could be due to

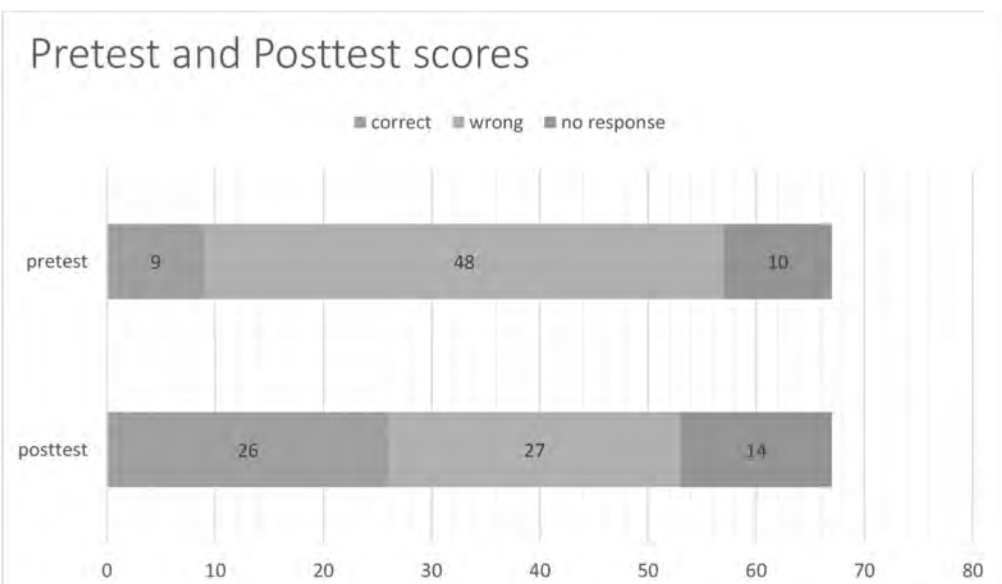


Figure 7. Understanding of scientific data. Stacked bar chart for student scores in the pretest (top) and the posttest (bottom). Each bar showing the number of student answers that were correct (blue), wrong (light orange), or "no response" (green). "No response" means that students did not even try to sketch in a correlation or that they crossed out what they had sketched in.

limited time at the end of the lesson, to the lengths of the test or to repetitive questions in the pretest–posttest design, which could seem kind of redundant or unnecessary to the students.

Learning Gain and Improved Skills

The findings of our case study demonstrate significant learning gain in the pretest–posttest design and a significantly improved understanding of scientific data. Despite our rather small sample size, we were able to include students from different types of school and can now draw conclusions about the effectiveness of our innovative teaching approach.

The majority of students didn't solve the task of visualizing correlations in the pretest, which aligns with studies showing that students are not sufficiently prepared to analyze quantitative data not getting enough opportunities to practice it in school (Rubin, 2005). As working with numbers and statistics as well as reading simple graphs and tables is common in math courses, the school curriculum lacks the opportunity for students to learn to critically analyze interdisciplinary data that have implications for their lives (Rubin, 2005). This is because school subjects are very much separated from each other always operating on a tight schedule (Swan et al., 2009). Technology is also essential for learning data analysis but is not very common and also not always accessible for school settings (Rubin, 2005). Here, some concrete difficulties, when dealing with the task became obvious in the pretest: (1) Study participants had to carefully read the instructions in order to understand the ecological experiment from which their data had been hypothetically collected. (2) Then, they had to carefully read the given correlation ("the higher the light intensity the higher the CO_2 consumption") to realize, that this doesn't mean that both variables increase, but as one goes up, the other one goes down. (3) Andfinally, to solve the task correctly, it was necessary to know the difference between falling curves and rising curves and to note that a decreasing CO_2 concentration following an increasing light intensity means a falling curve (see Figure 8).

Despite the significant learning gain concerning this task, 14 students didn't even try the task. This could be due to the repetitive character of the pretest–posttest design, which might be tiring for students. Twenty-seven students still answered wrong, which can be linked to the short time frame of our teaching unit. The students seem to be lacking the theoretical basis of data analysis, which cannot be overcome by a short and practical intervention. Moreover, it is very common in classes that there will always be some students who do not want to follow the instructions or are not able to keep up.

In order to complete their tasks in our teaching unit, students had to measure data themselves, and no matter which experiment they were assigned to, they had to measure CO_2 concentration and analyze the data. Among others, they had to set up one experiment exactly like the hypothetical experiment in the task instructions and have therefore seen and analyzed falling levels of CO_2 when light intensity goes up.

As the implementation of practical approaches in schools makes science tangible for students (Finn et al., 2002), we align our significant correlation between pretest and posttest regarding learning gain and understanding scientific data to practicing the skills of data acquisition and data analysis with technical tools in the classroom. This outcome is consistent with the finding from Lee and Thomas showing that elementary school students who have used sensors themselves to work with data outperform the control group in the knowledge test (Lee & Thomas, 2011). Acquiring and improving these skills in school are regarded crucial to be prepared for today's data-reliant society where data are used, for example, for evidence or as a tool for innovation (Wolff et al., 2016).

Limitations and Directions for Further Research

It has proven to be difficult to generate a large study sample for our purpose. Teachers who teach at the secondary level are often on a tight schedule, more than ever during the Covid-19 pandemic. Therefore, they refuse to implement additional content into their classes, which are often also very small (15–20 students). The aim here is that schools have to be provided logistically with the technical equipment of which there only is a sufficient amount for one class at a time which means, interventions cannot take place simultaneously. To generate large study samples, more time and more technical equipment are needed.

○ Conclusion

Practical approaches with hands-on materials are beneficial for students' motivation and learning gain and encourage understanding of environmental issues especially in times of a changing

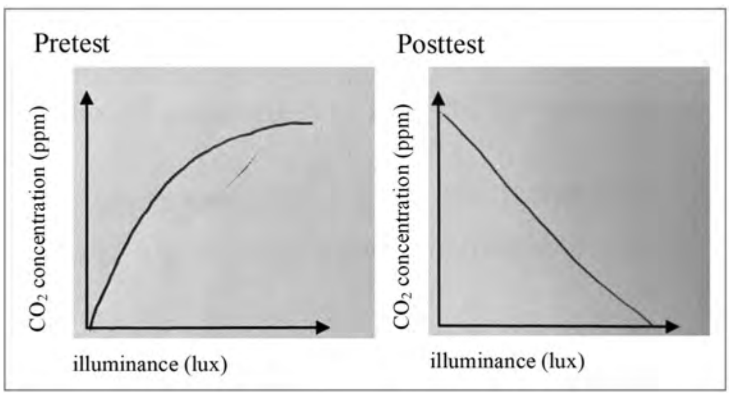


Figure 8. Students example of solving the task. Left side: Illustrative result of the pretest. The student did not correctly sketch in the correlation between CO_2 concentration and light flux as the concentration of CO_2 in a closed system with a green plant has to decrease with an increase in light flux due to the plants increasing CO_2 assimilation. On the right side (posttest), it has been done correctly.

environment. Our case study of an innovative teaching technique shows that wireless sensors have a great potential for school lessons as they encourage science classes orientation to research. Moreover, sensors could be applied to other biological contexts like ecosystem research or behavioral science and expand interdisciplinary to subjects like chemistry. In terms of our project *WinUM 2.0*, the vineyard as an ecosystem is exploited using various methods and materials. The teaching unit presented in this study lays the foundation for students to be able to collect and analyze data outdoors in the real ecosystem using the convenient and wireless equipment as they have already practiced handling the equipment and analyzing the data during the classroom experiments.

○ Acknowledgments

The authors are very grateful to the teachers who implemented the teaching unit in their biology lessons. In addition to that the authors thank all participating students for working with the materials and the technical equipment as well as cooperating in empirical testing and evaluation.

○ Conflicts of Interest

There is no potential conflict of interest to declare.

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