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Integrating Mathematical Modelling into Problem Based Research: An Evaporation Activity

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ABSTRACT

Climate change put most species' survival in danger because it substantially affects the climate in which the species live, the quality of the water they drink, as well as the temperature of the air or water. When climate change increases the temperature of the climate, excessive evaporation occurs in lands, lakes, seas, and oceans. Our purpose in this paper is to introduce a mathematical modelling activity embedded in Problem Based Learning (PBL) that allows students to investigate factors related to evaporation. Mathematical modelling is a popular technique of teaching mathematic concepts and skills and a method of inquiry about scientific phenomena that interests scientists. In the present activity, students use secondary data from trusted websites to test their hypotheses. Students are engaged in analyzing and interpreting data, generating and testing models, and discussing and presenting findings with their peers. The activity allows students the opportunity to examine the relationship between variables and predict one variable using the other. The activity has the potential to foster students' computational and higher-order thinking skills.

Keywords: Problem Based Learning (PBL), Mathematical Modelling, Climate Change, Evaporation, Authentic Science

INTRODUCTION

Climate change jeopardizes the survival of most living forms on the Earth by altering global and regional climates, the water cycle, and the food chain. While some people still

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believe that climate change is a part of a natural cycle, scientific investigations have shown that humans played a major role in causing the current climate change in the Earth. In the geological records, one can observe the changes in the Earth's climate in a very long time. In the current climate change though, the rate and magnitude of the changes are faster and more severe than the ones in the geological records, which raises many concerns. For this reason, many countries are implementing policies to address climate change, regulating their economy, production, energy, and education sectors to mitigate its impact.

One effect of climate change is unusual and extreme weather events, including high temperature, extreme precipitation, or lack of precipitation, which can lead to excessive evaporation (Yoro & Daramola, 2020). While evaporation is a crucial part of the water cycle, excessive evaporation due to climate change reduces the amount of water available in soils and lakes, which are the essential sources of drinking and irrigation water (Mhawej et al., 2020). Because excessive evaporation has negative consequences on human life and the environment in many ways, teaching factors related to and how to control excessive evaporation are very important to cultivate an awareness of climate change.

Evaporation is a major topic in science education that serves as a foundation for understanding other essential concepts and explaining daily phenomena. However, teaching about water evaporation is challenging due to its abstract nature and the need to consider both macroscopic and microscopic levels of understanding (Wang & Tseng, 2018). Despite the fact that the concept of evaporation is introduced in the third grade of the National Science Curriculum in Turkiye, studies have shown that students at different levels and pre-service teachers have misconceptions about evaporation. These misconceptions include beliefs that "evaporated water disappears" (Tsikalas et al., 2014) and that "evaporation is a chemical reaction" (Hämälä-Braskén, Hemmi, & Kurtén, 2020). Furthermore, there are misconceptions about the factors that affect evaporation, for example, the belief that "heating is necessary for evaporation" (Karsly & Ayas, 2013), and "air current decreases the evaporation" (Coştu et al., 2010).

To address the aforementioned misconceptions and improve understanding of evaporation, different teaching and learning approaches have been utilized, for example, inquiry-based instruction, argumentation, and conceptual-change strategy. However, due to the COVID-19 pandemic's lockdown, most instruction has shifted to virtual or online classrooms, which poses challenges for implementing these approaches. Wang and Tseng (2018) compared the effectiveness of virtual, physical, and virtual-physical instruction on third-grade students' understanding of the change of state of matters, and found that virtual and virtual-physical instruction were more effective than physical instruction. Furthermore, most studies on evaporation have focused on what evaporation is, rather than what factors could influence evaporation. There is a need to teach about the factors that influence evaporation in non-physical classrooms. Mathematical modeling can be an effective approach for teaching about these as it involves defining variables and modeling the relations among them. This approach can be implemented in virtual or online classrooms, yet there are no studies that have utilized mathematical modeling to teach about the factors that influence evaporation. Thus, in this case study, we aimed to address this gap.

Our purpose in this paper is to introduce a Problem Based Learning (PBL) activity that incorporates mathematical modelling and enables students to investigate factors related to evaporation. PBL involves solving a real world complex problem and encourages students to learn with self-direction and collaboration (Johansson et al., 2020). Mathematical modelling instruction focuses on a real world problem, collaborative work, and sharing the outcomes with peers. Collaboration among scientists and peer review process are some major components of authentic scientific research (Ayar et al. 2014). Collectivist nature of science refers to the collaborative characteristics of the scientific practice. Sociological nature of science refers to the peer review and argumentation processes of scientific research. Both the collectivist and sociological nature of science are often ignored in school science classrooms.

Scientists use mathematical modelling across a wide range of scientific disciplines, including medicine, engineering, chemistry to social sciences economics, and education (Kaiser, 2020). Mathematical modelling enables scientists to predict and formulate the relations between variables of interest. Moreover, mathematical modelling is a popular instructional technique to teach mathematical concepts and skills in mathematics education (Erbas et al., 2014).

The activity we describe in this paper uses mathematical modeling in a manner similar to how scientists carry out their research. When students engage in authentic research activities, they are more likely to develop an accurate understanding of science and scientific enterprise. Many studies in the learning sciences have shown positive correlations between conducting authentic scientific activities and improved understanding of science and its enterprise (e.g., Ayar & Yalvac, 2010; 2016). In the present activity, students are asked to analyze and interpret data, generate and test models, and present and discuss their findings with their peers. Furthermore, because in the activity students examine the relationships between variables and predict one variable based on the other, it has the potential to cultivate higher order thinking and computational skills. The activity we describe here is an integrated activity that science and mathematical concepts and skills are merged to support students' intellectual and cognitive development in both areas (Alpaslan, 2017; Işık & Alpaslan, 2018).

As more online instruction is being implemented in recent years, many students lack the opportunities to be physically present in a laboratory setting and collect data directly from their experimental setup. Even when the students are able to attend physical laboratory settings, real world data related to climate change or evaporation cycle need to be collected from sources other than the location of the laboratory or the classroom. Using secondary data is an alternative to conduct authentic scientific investigations for students who are studying in their home locations and students who can attend physical laboratory or classroom settings. Trusted websites exist where students can obtain data they need for their scientific investigations. As with the present activity, it can be implemented in virtual classrooms at the students' locations because students utilize the data found on the Internet.

BACKGROUND

Evaporation

The International Glossary of Hydrology defines evaporation as the process of water changing from a liquid to a vapour at temperatures below boiling point" (International Glossary of Hydrology, 2012, p.114). Every surface on planet Earth that contains liquid water is the source of water vapour in the atmosphere. Continuous evaporation occurs on seas, lakes, streams, moist soils, snow-covered or ice-covered surfaces, and forests (Tao et al., 2018). Evaporation is an important part of the water cycle. The amount of water that evaporates on a global scale is equal to the amount of water that falls on the Earth as precipitation. With the effect of climate change, excessive evaporation can cause the unbalanced rainfall across the Earth at where some regions suffer heavy precipitation as rain or snow and some other regions would face the absence of precipitation and eventually drought. Therefore it is important to teach students about the factors related to evaporation and how to control it.

Mathematical modelling

Mathematics is a branch of science that emerged from the need to produce solutions to daily problems. It has provided the foundations of other scientific disciplines. Mathematics is a language that humans constantly use to express and solve their daily needs (Erbas et al., 2014). Mathematical modelling is the process of expressing the relationships between situations mathematically, whether directly related to mathematics or not, and creating mathematical patterns within those situations. Mathematical modelling is an effective tool for fostering creativity and problem-solving, allowing individuals to make interdisciplinary connections and apply what they have learned in their daily life.

The present activity follows a mathematical modelling process that consists of five stages as defined by Erbas et al. (2014). These stages are (a) defining and simplifying the real-life problem, (b) creating a mathematical model, (c) transforming, developing, and solving the model, (d) interpreting the model, and (e) validating and using the model. This process is iterative and non-linear. In the fifth stage, students have the opportunity to re-examine their research question, which fosters a feeling of ownership and belonging, thus increasing their motivation and engagement in the research. The present activity is designed based on this five-stage process. Haines and Crouch (2007) also defined mathematical modelling as a cyclical process, in which real-life problems are abstracted into mathematical language, analyzed, and the solution found is tested.

ACTIVITY

This activity is suitable for high school students and pre-service teachers who will be teaching at the high school level. It can be completed within two class hours (90 minutes total). In Table 1, we illustrate the connection between the objectives of the activity and the Next Generation Science Standards (NGSS Lead States. 2013). We asked 19 pre-service science teachers to complete this activity as if they are students whom they will be teaching. The pre-service teachers were grouped into teams of three to four individuals and worked collaboratively. The activity can be implemented in a physical classroom or in a virtual classroom (e.g., in Zoom), or can be given as a course project. In the present implementation of the activity, the participants worked in a virtual classroom environment (on Zoom with breakout rooms), which facilitated engagement more effectively because of the low number of participants per room.

Science And Engineering Practices	**Crosscutting Concepts**	**Disciplinary Core Idea**
Asking questions (for science) and defining problems (for engineering)	Cause and effect	HS-ESS2.D The role of radiation from the sun and its interactions with the atmosphere, ocean, and land are the foundation for the global climate system. Global climate models are used to predict future changes, including changes influenced by human behavior and natural factors
Obtaining, evaluating, and communicating information	Scale, proportion, and quantity	
Engaging in argument from evidence	Energy and matter: Flows, cycles, and conservation	

Using mathematics and computational thinking	HS- ESS3.D Global climate models used to predict changes continue to be improved, although discoveries about the global climate system are ongoing and continually needed.
Analyzing and interpreting data	
Developing and using models	HS-ESS3-5 Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth's systems.

Table 1. Connections of the activity to the next generation science standards.

To implement a mathematical modelling activity, data are expected to generate a mathematical connection between variables and test the mathematical model based on logical or theoretical connections. Secondary data, which are data collected by someone else and provided to the researchers can be used to provide the necessary conditions. Using trusted secondary data from organizations including OECD (PISA data), NASA and other government meteorological services is a common practice in scientific research and publications. In this activity, the Goverment's Meteorological Services data were used to form a mathematical model and test it. Many factors affect evaporation, including climatic and geographic factors and water characteristics. In the present activity, pre-service teachers were allowed to investigate the relationship between evaporation and the selected factor using available data.

Among the materials needed for this activity are a computer with Excel 2013 or above and Internet access. We used an Excel file that contained the instruction for group and individual work. In the beginning of the activity, we instructed the pre-service teachers how to create a scatter plot with the trend/regression line, which showed the mathematical equation between two variables based on the selected mathematical relation (linear, exponential, logarithmic, or polynomial). Further information about how to add a trend/regression line in Excel can be found at the Microsoft Excel support webpage (Microsoft, n.d.).

Stage One: Determining Participants' Pre-Existing Knowledge on Evaporation

Before the activity starts, we recommend exploring and documenting participants' pre-existing knowledge on evaporation. In our implementation, we asked our 19 pre-service teachers to answer several open-ended questions including "How do you define climate changing?," "How does climate changing affect our life and the earth?", "What is evaporation?", "What is the role of evaporation on water cycling?", "What is the role of evaporation on the water scarcity" and "What factors affect evaporation?". In addition to the open-ended questions, we used a two-tier diagnostic test. The test, developed by Karsli and Ayas (2017), comprised seven two-tier diagnostic questions (i.e., a multiple-choice question followed by its explanation) and intended to map respondents' understanding of evaporation. Our 19 pre-service teachers' responses showed that they had sufficient knowledge on the definition of evaporation and climate, but limited knowledge on explaining factors related to and how they could affect life on the Earth.

Stage Two: Problem Statement

A mathematical modelling activity starts with a daily problem (Erbas et al., 2014). At the first stage of the present activity, we provided our pre-service teachers with a problem statement that read:

> "A group of researchers would like to determine the amount of water that evaporates in a lake annually. Because the researchers cannot measure the amount of water in the entire lake, they conclude that it would be easier to determine the amount of evaporation with the help of a factor related to evaporation. For this, the researchers first have to determine a variable related to evaporation. Then, they want to obtain an equation using the data provided by the State's Meteorological Service. However, they have been reminded that humidity can be a factor that influences the evaporation; thus, they want to create mathematical models for three different humidity regions of the country. Please help the researchers to compute the evaporation in a lake located in the city."

Stage Three: Determining Variables and Predicting

After being given the problem statement, the 19 pre-service science teachers were asked to discuss in groups and determine a factor that they believed was related to evaporation. Participants were given ten minutes to make an Internet search and review the available reading from the State Meteorological Service website (https://mgm.gov.tr/arastirma/buharlasma.aspx; See Figure 1). There were five groups of students and they selected five variables, including temperature, wind speed, latitude, sun radiation, and the number of sunny days. After selecting the variables, the students were asked to predict the relationships among them (whether it would be directly or inversely linear, logarithmic, or non-related).

Next, the students used the data from the State's Meteorological Services website and entered them in Excel. They created a scatter plot with a trend line for three different climate regions. There are various climate classification approaches in the literature, for example, Köppen climate classification and Thornthwaite climate classification. Each approach uses different parameters, for example, temperature and annual precipitation. In this activity, the Thornthwaite climate classification was used because it considers evaporation and humidity in climate classification (MGM, 2017). The full climate list of the provinces was given to the students in the handout.

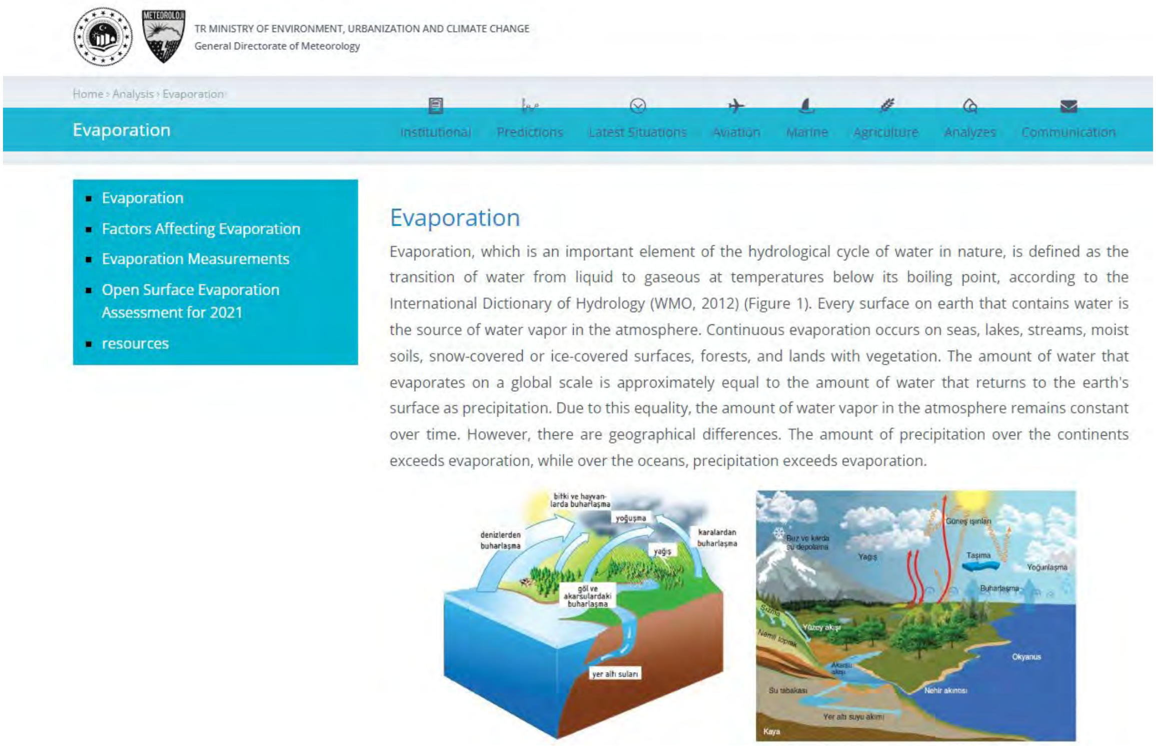


Figure 1. A screenshot of the MGM website on evaporation.

Stage Four: Creating a Mathematical Formulation

The students were asked to take note of the equations from the trend lines of the scatter plots for three regions. In groups, students discussed the following questions: “What kind of equation (e.g., linear, logarithmic, or other) did you obtain?” and “What you can tell about the relationships between evaporation and the variables you investigated?” The students usually created a linear relationship between variables. Students’ responses indicated that they generally interpreted the equation as an inverse or direct proportion. One example of the graphs students obtained was the relationship between latitude and evaporation as shown in Figure 2. Students concluded that when latitude increases evaporation decreases.

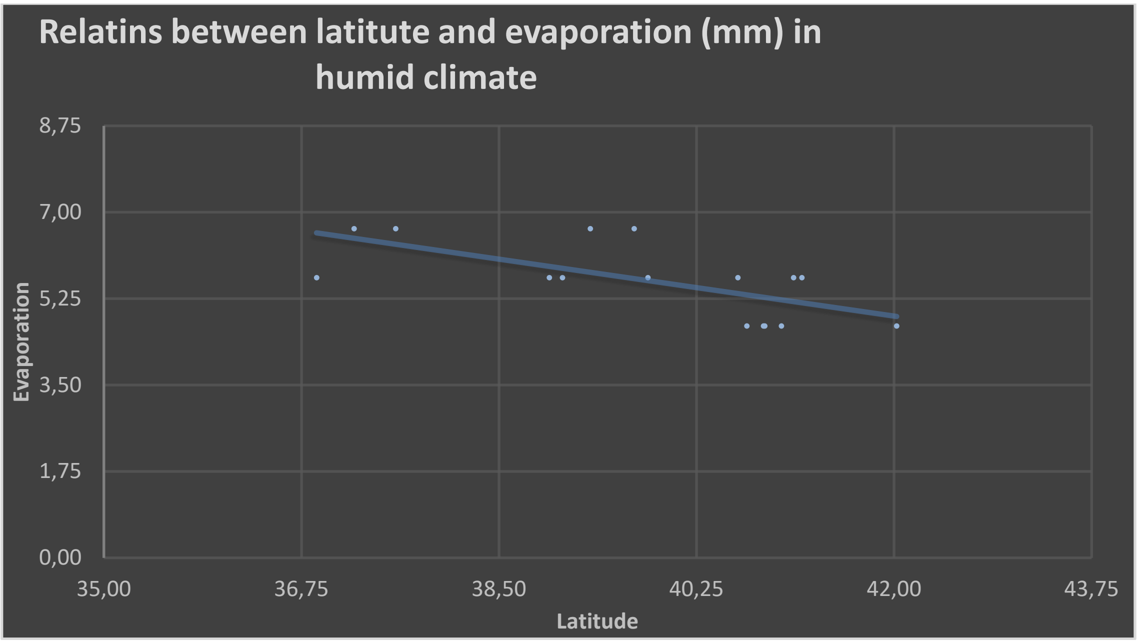
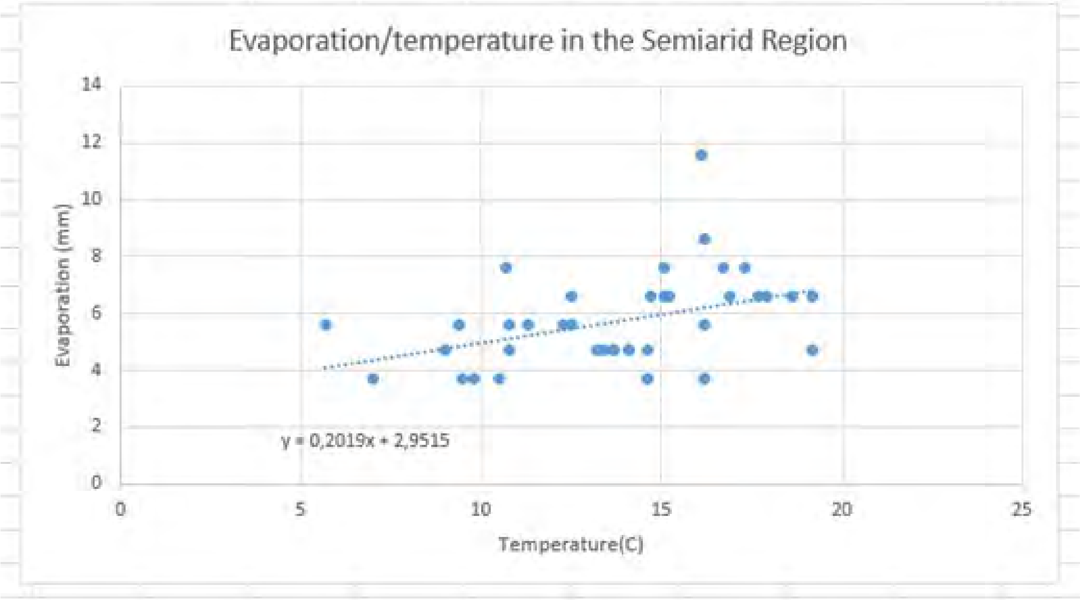


Figure 2. An example of students' work at stage 4.

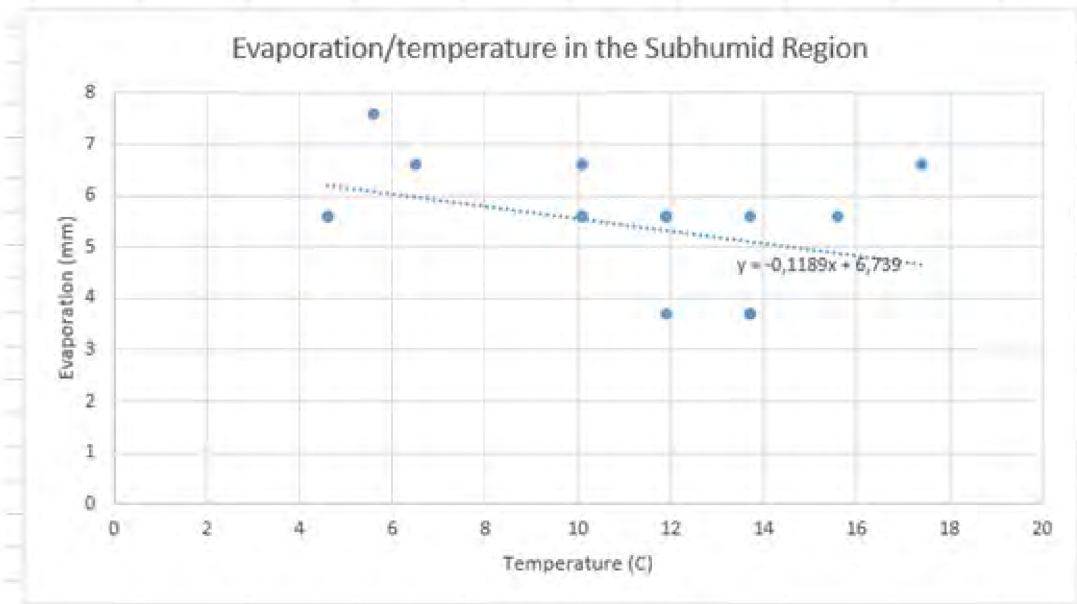
Stage Five: Validating the Mathematical Model

The next stage of the mathematical modelling is to validate and evaluate the mathematical model. If the model fails, the students should go back to stage three or four. At this stage, the students were asked to compare the mathematical models of three different regions of the country and determine if the equations were similar across the regions. They were asked to explain why the equations were different if they were, and to choose the best one. Humidity is one of the most critical factors affecting evaporation because it is related to the saturation degree of water in the air. Thus, students were more likely to obtain different mathematical equations across the three climate regions of the country.

Moreover, some groups found a reverse relation between evaporation and the variables. For instance, as seen in Figure 3, one group who examined the relation between temperature and evaporation found that the direction of the relationship between the two variables reversed across climate regions. In some arid climate regions, the relationship was directly proportional whereas in the humid climate region it was inversely proportional. This was a good result that allowed the students discuss the effect of the climate and to demonstrate how scientists can come up with different solutions for the same phenomenon. The students were asked to use the mathematical equation to find evaporation in a city of their choice and evaluate their equations. Based on their errors, they were to discuss and choose the best mathematical model.



a)



b)

Figure 3. a) The relation between temperature and evaporation was directly proportional in arid regions. b) The relation between temperature and evaporation was inversely proportional.

Stage Six: Output and Assessment

At the last stage of the activity, students were given some time to prepare their presentations. They were asked to include how they chose the variable, their guesses, and findings with graphs and equations. Students presented their ideas about the error of the models and how they justified their mathematical models for three climatic regions of the country. In addition, they shared their ideas about how to minimize evaporation. Some groups suggested building the windmills for generating energy at the edge of lakes so that it would reduce velocity of the wind and lessen the evaporation. The two-tier diagnostic test was re-applied. It was seen that students did well in the post-test compared to the pre-test. Their mean score increased from 3.7 (SD=.32) to 5.3 (SD= .49). A paired sample t-test showed that there was a statistically significant difference in favor of the post-test.

CONCLUSION

In the present study, our purpose has been to introduce a mathematical modelling activity to teach evaporation and related factors. In the activity, the students determined a variable, predicted its relationship with evaporation, collected and analyzed data with graphs, created a mathematical formula to show the relations between variables, and interpret and verified the formula for a particular situation. This activity has potential to increase awareness of how scientists work. This activity can be used to teach various subjects. We are in the age of the Internet and there are many different data resources that are freely available online. For instance, there are open data and educational resources to teach climate at the National Oceanic and Atmospheric Administration website (National Oceanic and Atmospheric Administration, 2018). Available data can be used to teach various science concepts related to climate change.

One thing should be noted that the connection between variables should rely on the logic, rationale, or theory. Any numbers can be related but it does not show that these variables are related to each other in reality. Therefore, it is important to give some time to students to do research or to provide materials on the links between variables. In this activity, students were given some time to read information and related factors on the State Meteorological Service website (See Stage 3). Also, it is important to let the students write their hypotheses so that they can really see what they are doing.

Another caution is that the instructor should know students' mathematical abilities. Although the mathematical models in evaporation are complex, we simplified it in the activity including one independent variable. High school or college students can easily recognize the graphical relationships of a logarithmic, inverse, direct proportion, etc. However, it is beneficial to let students discuss how the mathematical models in environmental science would be.

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