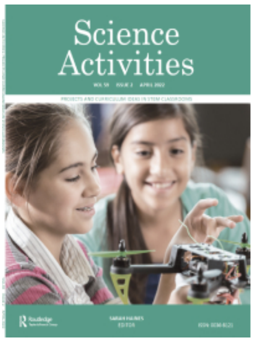

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Protecting our WATERS: A 5E lesson sequence derived from a National Science Foundation-funded middle school watershed sustainability curriculum

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ABSTRACT

Oftentimes, due to the involute nature of the issues involved, society leaves it up to the experts to tackle the environmental problems currently facing society. However, a more wholistic approach is needed to address these environmental issues in the timely fashion necessary. With a reductionist treatment of sustainable development issues, the concepts involved can be broken down to a level accessible by the public. WATERS: Watershed Awareness using Technology and Environmental Research for Sustainability, is a 10-lesson watershed sustainability curriculum directed at middle school students. Using online, classroom, and field-based components, WATERS seeks to make watershed sustainability and conservation an accessible topic for students around the United States, hoping to create a generation of Environmentally Literate citizens who have the knowledge and desire to tackle the pressing issues facing the natural world around them. While the complete WATERS curriculum consists of ten lessons, this article will describe a 5E sequence that consists of four of the ten lessons.

KEYWORDS

Meaningful Watershed Educational Experiences (MWEEs); virtual learning; environmental education; environmental literacy; 5E model; sustainability education

Introduction

The concept of sustainability and sustainable development are both complex interdisciplinary understandings required when dealing with the interconnected environmental issues facing society in the 21st century. Rees (1989) defines "sustainable development" as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Oftentimes, due to the involute nature of the issues involved and the interconnectedness of sustainability, society leaves it up to the experts to tackle this task. However, a more wholistic approach is needed to address these environmental issues in a timely fashion. "The educational system can be more powerful in promoting changes than regulatory and market-based systems…when it comes to forming future generations of citizens who are either willing to change their attitudes and behavior, or else at least accept policies aimed at steering society in a more sustainable direction" (Andersson et al. 2013). With a reductionist treatment of sustainable development issues, the concepts involved can be broken down to a level accessible by the public. WATERS: Watershed Awareness using Technology and Environmental Research for Sustainability, is a 10-lesson watershed sustainability curriculum directed at middle school students. While many aspects of sustainability are regional or local, every person on earth lives in a watershed. Using online, classroom, and field-based components, WATERS seeks to make watershed sustainability and conservation an accessible topic for students around the United States. With this curriculum, we hope to create

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a generation of Environmentally Literate citizens who have the knowledge and desire to tackle the pressing issues facing the natural world around them.

The WATERS curriculum includes a grant-funded online student learning portal/course management system that serves as a repository for lesson directions, student readings, instructional videos, career exploration, and embedded online simulations and models. These simulations and models allow the students to explore topics such as runoff, permeability, infiltration, and evapotranspiration while investigating how various sustainable development strategies and best management practices may impact the health of watersheds (e.g., rain gardens, pervious surfaces, wetlands, etc.), and addressing "the basic premise of sustainable development, that human and natural systems are dynamically interdependent and cannot be considered in isolation in order to resolve critical issues" (Dale and Newman 2005). Students are even able to explore how their own watershed would be impacted by these strategies. With the knowledge gained from these tools, students are equipped to make informed sustainable development decisions regarding their local environment and are tasked with creating an environmental action plan. Through the coupled use of these models/simulations and environmental action plans, along with a guided schoolyard walk, WATERS makes watershed sustainability and conservation topics both accessible and usable for students at the middle school level.

Background on the curriculum

The WATERS curriculum is an inquiry-based curriculum that can be taught in whole or in part. The following describes how the WATERS curriculum can be adapted to 4 lessons that adhere to the 5E instructional model. This 4-lesson sequence is usable for students in grades 6-10 and in classes of all sizes. Constructivist inquiry-based instruction has been shown to positively impact students' scientific reasoning and scientific inquiry abilities (e.g., asking questions, designing experiments, developing and communicating scientific explanations) (Johnson and Lawson 1998) and "the sustained use of an effective, research-based instructional model can help students learn fundamental concepts in science and other domains" (Bybee 2006, 1).

The 5E model includes five phases: Engage, Explore, Explain, Elaborate, and Evaluate (see Figure 1). Students move linearly through the first four steps while evaluation can take place at any or all stages.

Aligned to the Next Generation Science Standards (NGSS) (see Table 1), the WATERS curriculum uses the 5E instructional model to lead students through an investigation of the students' local watershed. Investigating local

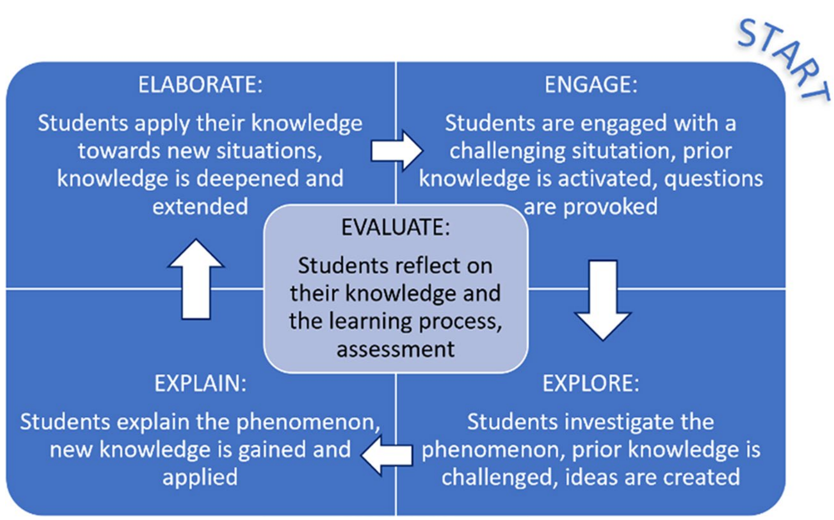

Figure 1. Descriptions of each step in, and sequence of, the 5E Model of Instruction (Northern 2019).

Table 1. Next Generation Science Standards (NGSS) alignment.

Performance expectations:	HS-ESS2-2 Analyze geoscience data to make a claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	
Science and engineering practices	Disciplinary core ideas	Crosscutting concepts
Developing and using models	ESS2.C The roles of water in Earth's surface processes	Systems and system models
Constructing explanations and designing solutions	ESS3.C Human impacts on Earth's systems	Patterns
Analyzing and interpreting data	ETS1.B: Developing possible solutions	Cause and effect

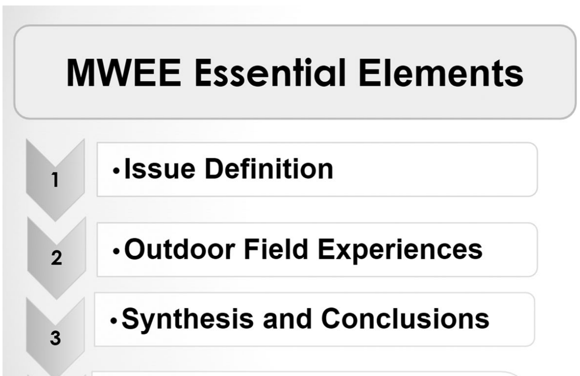

Figure 2. MWEE essential elements.

environmental issues that lead to informed action and civic engagement is at the heart of NOAA's Meaningful Watershed Education Experience (MWEE) framework (see Figure 2) (NOAA 2017). Used together, the 5E instructional model and the MWEE framework support authentic hands-on learning of students' local watershed. While the complete WATERS curriculum consists of ten lessons, this article will describe a 5E sequence that consists of four of the ten lessons (referred to as the "four-lesson sequence"). The goal of this four-lesson sequence is to inform students about various strategies used to promote sustainability in watersheds, teach them about what problems exist in their local watershed and what strategies are being used to address them, help them model potential solutions to problems that still exist, and guide them in drafting an action plan to address a local watershed problem.

Lesson 1: Engage—Identifying the local problems and providing knowledge, the schoolyard walk (45 minutes)

Students start this lesson sequence with a series of readings providing students with content knowledge on various watershed conservation/sustainable development strategies such as rain gardens, porous paving, green roofs, no-till agriculture, planting of trees along streams, and others. Students are subsequently broken into teams (of approximately four students per team) and instructed to investigate a single conservation practice further, after which, they will present a brief one-minute summary of the practice to the class, allowing for evaluation via formative assessment at the early stage. For additional formative assessment, teachers can choose to have the students record and submit their answers to questions as they proceed through the virtual lessons.

Now that students have a grasp of various conservation strategies, the class is taken outside for a guided schoolyard walk during which groups are instructed to be on the lookout for their assigned conservation practice. Throughout this activity, students use a teacher-provided printout map of their schoolyard to color current conservation practices identified throughout the tour. Students also put their newfound knowledge of perviousness to use by mapping the areas of pervious and impervious surfaces. During this walk, students are further Engaging with the idea of watershed conservation and sustainable development by connecting the concepts they just learned with their own schoolyard. Additionally, the teacher will provide further information and address questions about conservation features spotted around the schoolyard throughout the walk. When concepts are applied to the real world, it helps to "legitimise the learning of concepts from the students' perspectives, which is more likely to make their learning intrinsically meaningful" (King and Ritchie 2012).

Upon returning to the classroom, students discuss their findings with the class and identify areas that would benefit from installation of a conservation feature. Students are now, ideally fully engaged with the concept of watershed sustainable development after using their knowledge to identify and suggest possible solutions for areas around their own schoolyard that could use improvement.

Lessons 2 & 3: Explore and explain—Deepening students' understanding of the problems and modeling the possible solutions (90 minutes)

"Technology as a tool for exploring concepts and ideas can help bridge the content and pedagogy so to provide an ideal learning environment for all… Experiences where real content concepts, principles, rules, and problem solving (Gagné as cited in Enderson and Watson 2019) can be explored, tested, or observed are critical to teachers fully embracing the power of technology in classroom instruction (Gorder; Lee et al. 2010; Li & Ma as cited in Enderson and Watson 2019). Modeling and simulation tools allow such environments to be a part of the learning process which promote dynamic experiences rather than static presentation of concepts" (Enderson and Watson 2019). In this four-lesson sequence, the next two lessons each take students through a separate, but related, Explore and Explain sequence during which they deepen their understandings of the issues they identified during the schoolyard walk—as well as the relevancy of these issues—and use technology to model the possible solutions they suggested. This is accomplished through the use of two online applications/models: Model My Watershed's Runoff Simulation and Site Storm Model.

The runoff simulation

The Runoff Simulation is an online tool that allows students to discover how land cover and soil type (Hydrologic Soil Group) affect the movement of water during a 24-hour storm event (see Figure 3).

For a specialized lesson, including a worksheet, for the Runoff Simulation, click here, or see Appendix A (Supplementary material) (Stroud Water Research Center, Inc 2022). Students use the Runoff Simulation interactive model to investigate how the type of land cover, amount of rainfall, and soil type (Hydrologic Soil Group) affect where water goes when it rains. The Runoff

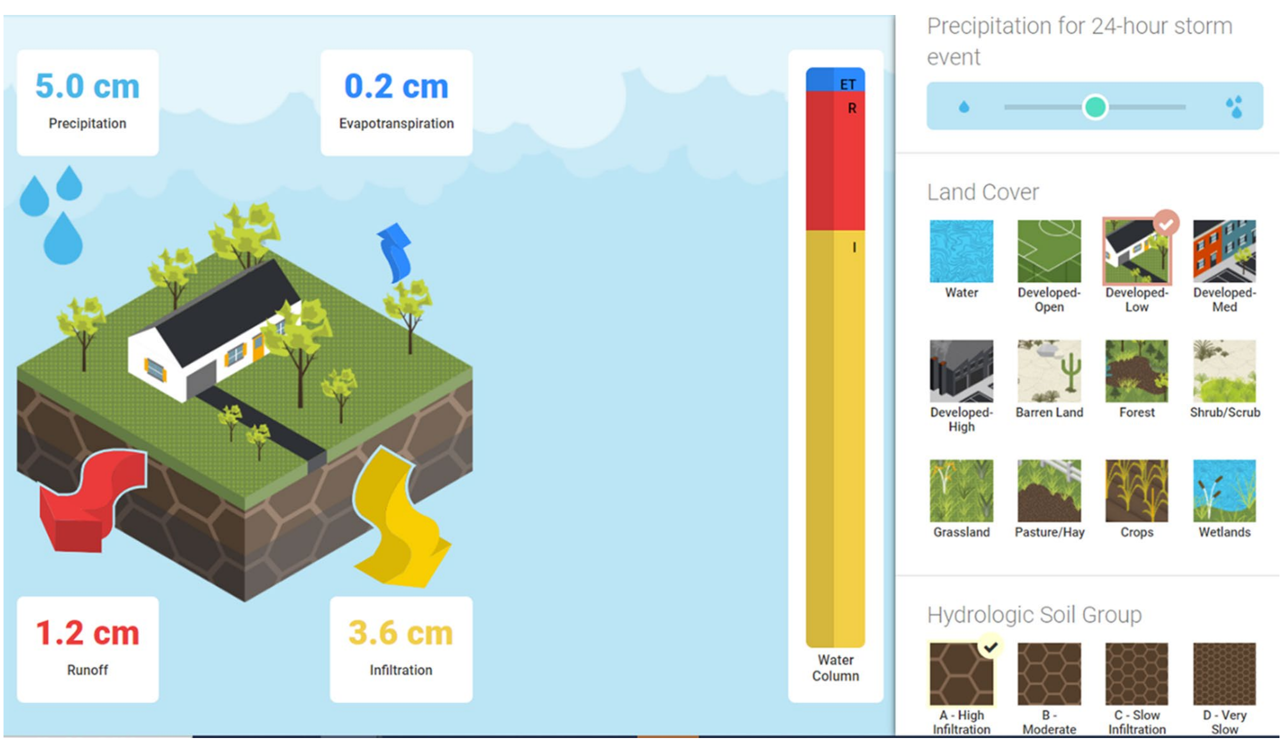

Figure 3. The runoff simulation: https://runoff.modelmywatershed.org/.

Simulation includes a main graphic showing a parcel of land with Evapotranspiration, Infiltration, and Runoff results indicated, and a control panel on the right side for the variables in the model that can be manipulated. Users can change the amount of precipitation for a 24-hour storm event by adjusting the slider at the top of the variable control panel (blue oval) on the right side of the Runoff Simulation. The results are immediately calculated and shown in the simulation. Land Cover (green oval) options are found below the precipitation slider. Descriptions can be seen by hovering the cursor over one of the 12 Land Cover types, and the user can click any Land Cover to change this variable in the simulation. Hydrologic Soil Group (red oval on the bottom of the variable control panel) works the same way—descriptions can be seen and Soil Groups can be selected with the cursor, which results in a recalculation and change in the model.

By changing land cover types, students are further Exploring the knowledge they gained about the effect of pervious and impervious surfaces on runoff during The Schoolyard Walk lesson. They use this knowledge to Explain the outcome of changes they make while Exploring the Simulation. By the end of using the Runoff Simulation, students have ideally used their knowledge of porosity to Explore how various changes affect a virtual world during a storm event as well as to Explain why these changes occur. Teacher Evaluation of students' ability to offer these Explanations can be facilitated through class discussion prior to implementing changes in the model as a group.

Site storm model

The Site Storm Model is a powerful online GIS (Geographic Information System) tool that includes real data from national databases for land cover, soil type, stream maps and data, water quality, and more (see Figure 4). The Site Storm Model is a professional grade application that can be used by teachers, students, land use planners, conservation planners, scientists, citizen science groups, and the public to understand how human activities and the installation of BMPs (Best Management Practices) can protect and conserve the quality of water in their watersheds. In this activity students will create scenarios to reduce runoff and improve infiltration by modifying the actual conditions at their location and developing a best land management proposal to protect the water quality in their local watershed (see Figure 5). Students should refer to the maps of the

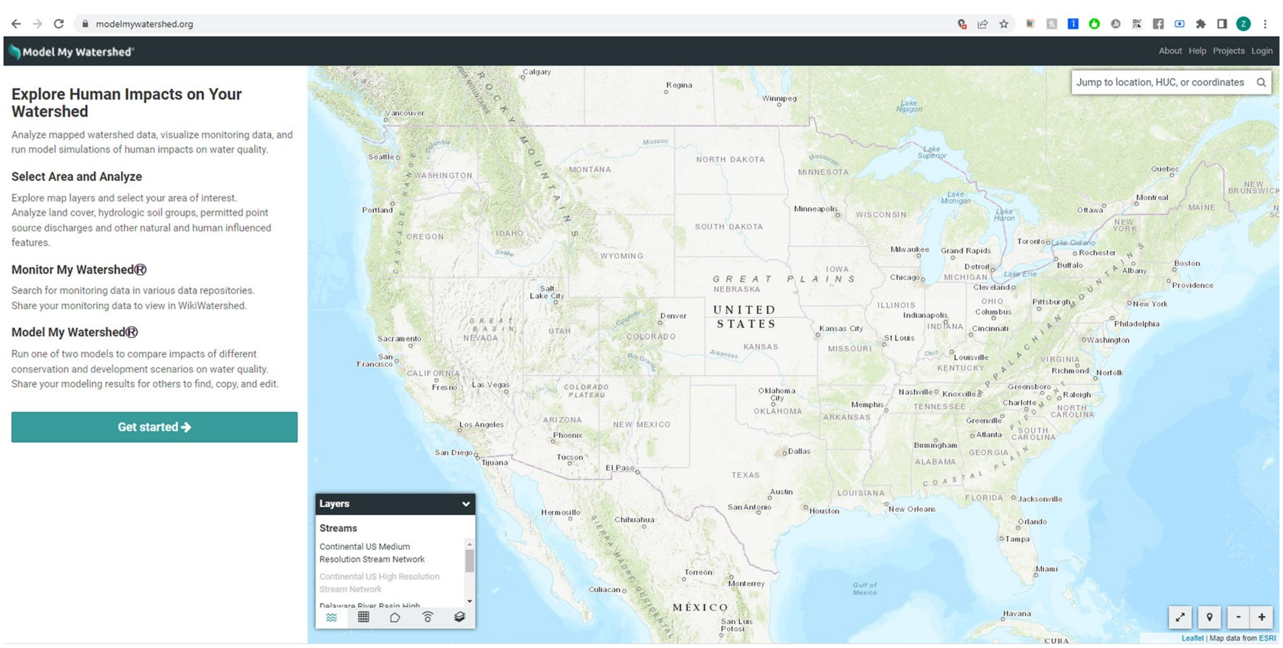

Figure 4. Landing page of The Site Storm model. Link: https://modelmywatershed.org/.

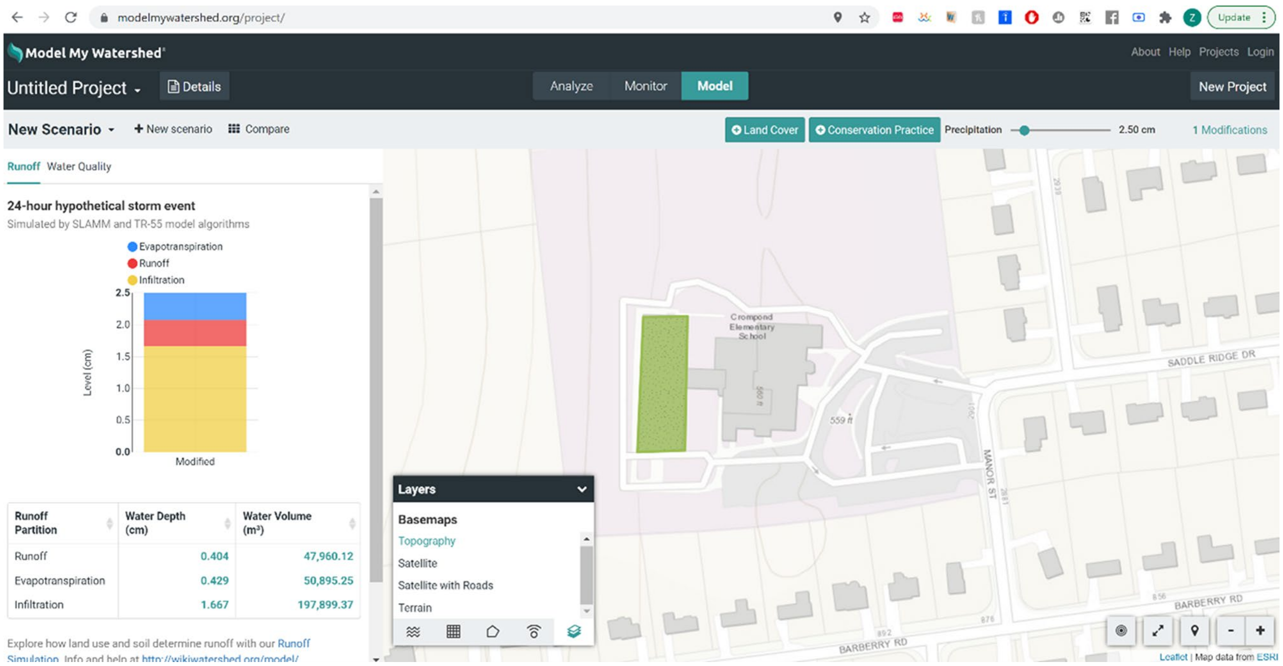

Figure 5. A user explores the effect on runoff, evapotranspiration, infiltration, and water quality from installing a green roof on their school, and porous paving in their schoolyard, using the Site Storm Model.

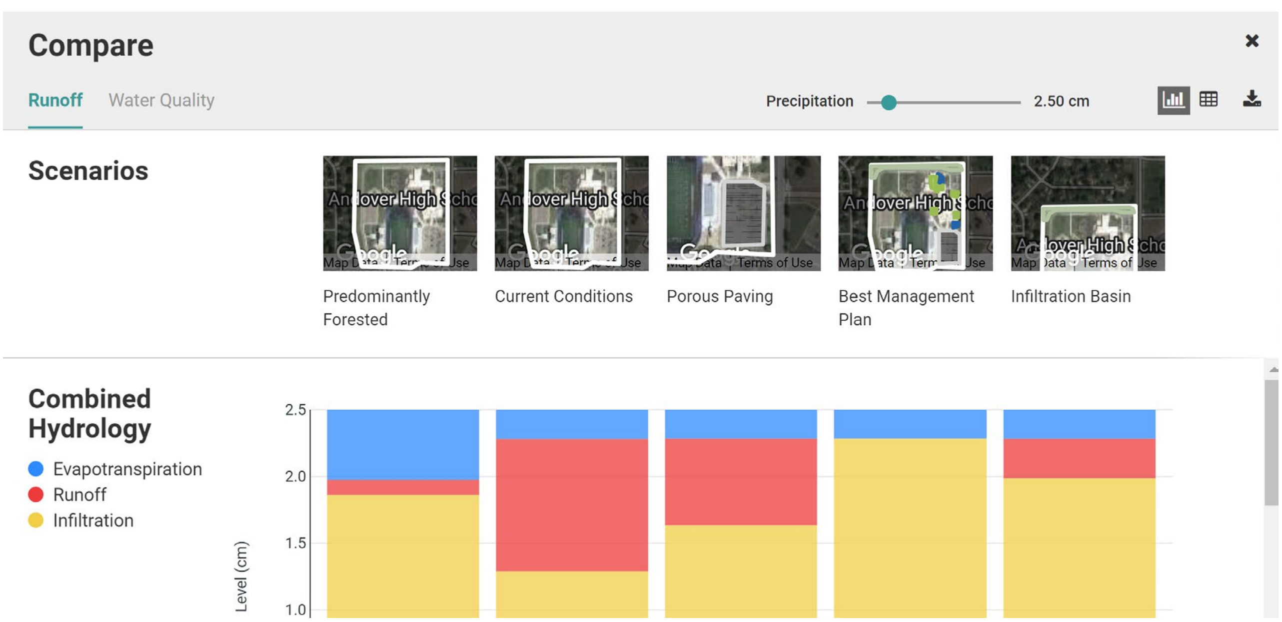

Figure 6. Table showing the effects on runoff, evapotranspiration, and infiltration from various conservation strategies students installed in the Site Storm Model.

school property that they made in The Schoolyard Walk lesson.

After Exploring the effect of making various virtual changes to their school property, students are provided with a table that depicts the modeled resulting effects on runoff, evapotranspiration, infiltration, and water quality from the respective changes they made (see Figure 6). They can use their new knowledge to Explain these results.

While using the Site Storm Model, students are able to assume the role of a civil engineer, simulating the kinds of sustainable development and watershed conservation decisions and modeling that go into architecting a building or area. They can apply the knowledge they gained in the previous two lessons to virtually address the issues and try out the solutions proposed during The Schoolyard Walk lesson.

Help resources, including individualized curricula, for both Model My Watershed's Site Storm Model and the Runoff Simulation can be found here: https://wikiwatershed.org/help/

Lesson 4: Elaborate—Roadmap to action! (90 minutes)

In the Elaborate stage of the 5E model, students stretch their new knowledge to broader applications and problem solving scenarios. In the culminating activity of this four-lesson sequence, students create an action plan. In this lesson, students will apply their new knowledge, working collaboratively with classmates to develop an action plan that addresses an environmental phenomenon, problem, or issue in their local community. There is freedom here for how the students should present/document their action. For example, one teacher who piloted this lesson had the students write their actions on post-it notes and put them on a poster in the front of the room so students could be reminded of their proposed action each day. Students can use Appendix B (Supplementary material) to lay out their action plan. An examplar has been provided as Appendix C (Supplementary material).

During this accelerated action plan project, students begin the process of creating positive change by identifying a local issue they care about, researching feasible solutions (positive actions), and developing an implementable action plan. Action projects transcend the learning process, empowering students to take active roles in improving their communities through their own positive decision-making. Teachers play critical roles as the gatekeepers of sensitive and productive student dialogue. Even when teachers lead question-based student discussions, students should independently explore and draw conclusions about the issues, solutions (actions), and project plans that are most personal to them, and what students themselves think are most likely to enact positive change. "The ultimate goal of environmental educators should be to facilitate the creation of this active citizenry. The means by which educators achieve this goal are equally important. Student autonomy in issue investigations and action planning should supplant coercive, advocacy programs if a new generation of critical thinkers is to solve new environmental problems and maintain or improve environmental quality on both the local and global scales" (Short, 2009).

Each class will focus on a single *problem area* in their watershed that they identified throughout the course of the previous three lessons (e.g., water quality). Student groups are then

Figure 7. A teacher implementing Lesson 4 assists students working in a group to form their action plan.

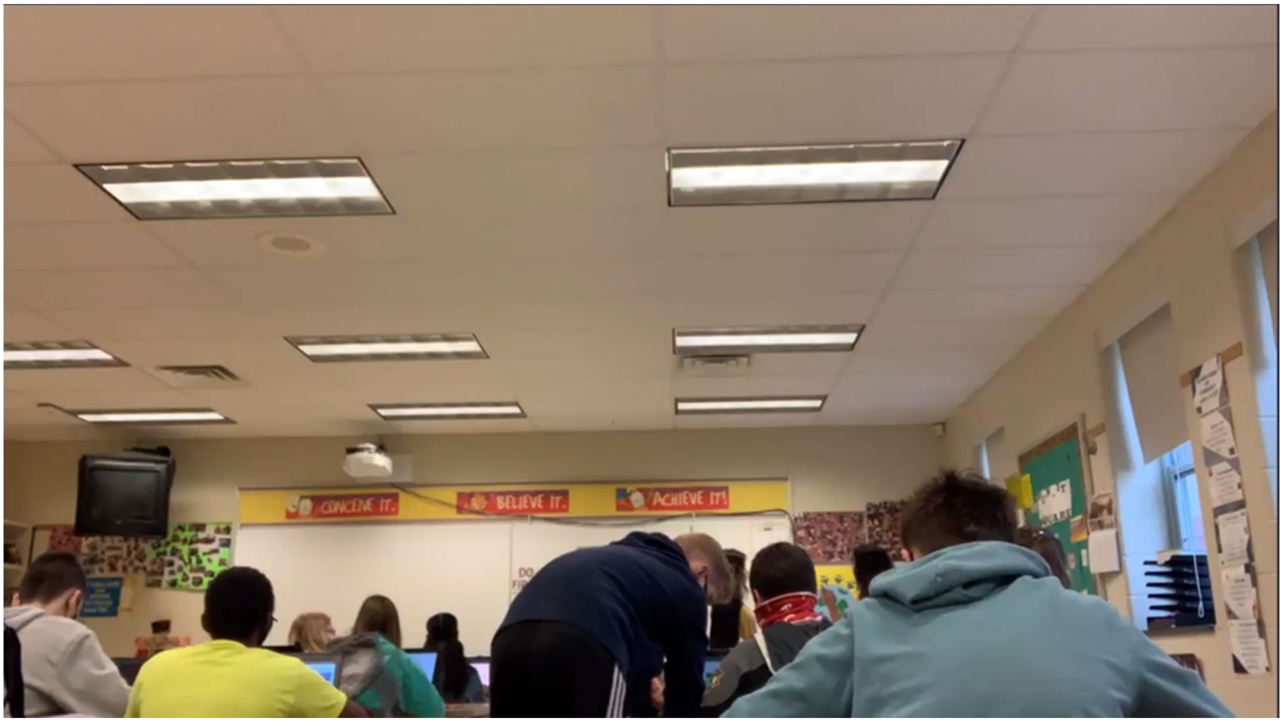

Figure 8. Students are observed assisting others in their group. In this case, the student standing in the navy sweatshirt was designated by the teacher as the "group leader" for his group. In this moment, he was observed suggesting that "green roofs could help absorb it [runoff] and help the roofs to not cave in because of the water."

encouraged to select a more specific *environmental issue (e.g., fertilizer runoff)* related to the identified problem area, one that they feel is important. Once each group has selected their environmental issue, they will choose a real-life solution (positive action) that will help them stop or improve the issue (e.g., use less fertilizer). The next, final, and most difficult step is for them to plan an action project that considers the materials, partnerships, money, and steps needed to make their project a success. Teachers should emphasize that the most important part of an action project, implementation, is missing. After creating the action plan, students will have had the opportunity to take what they have learned and Elaborate on the knowledge by applying it to a local problem of interest to them (Figures 7 and 8).

To conclude this four-lesson sequence, student groups will present their action plan to the class. As a method of evaluation, the Action Plan Presentation Checklist provided as Appendix D (Supplementary material) can be used by students to evaluate their classmates' projects as well as their own. This can be easily adapted by the teacher by assigning point values to each component.

Conclusion

Throughout this four-lesson sequence, students gained knowledge about watershed sustainability (Engage), expanded on this knowledge through the use of two online simulations/models (Explore), used these models to answer questions (Explain), synthesized their knowledge and expanded its applications by creating a local action plan (Elaborate), and were Evaluated at each stage. Students should not only leave this experience feeling like they have learned about their local watershed, but also leave feeling like they have the knowledge of how what they learned can be applied to a local environmental issue that they are passionate about. Through the use of students' local watershed as a case study, students have gained an appreciation "of the interrelationship between human and natural systems" (Dale and Newman 2005) that is necessary to making them one step closer to being the Environmentally Literate decision makers needed to progress our society in a sustainable fashion.

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