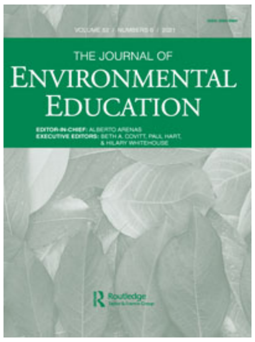

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RESEARCH ARTICLE

Model my watershed: an investigation into the role of big data, technology, and models in promoting student interest in watershed action

Nanette Marcum-Dietrich[a], Steve Kerlin[b], Amanda Hendrix[a], Nicole Sorhagen[a], Carolyn Staudt[c] and Zachary Krauss[a]

[a]Millersville University of Pennsylvania, Millersville, Pennsylvania, USA; [b]Stroud Water Research Center, Avondale, Pennsylvania, USA; [c]Concord Consortium, Concord, Massachusetts, USA

ABSTRACT

The Meaningful Watershed Educational Experience (MWEE) is a curriculum framework designed to support students' Environmental Literacy (E-Lit) by promoting critical thinking about watersheds, but there is a paucity of empirical evidence in the literature to demonstrate its effectiveness in increasing E-Lit and a lack of understanding of what MWEE instructional activities best support E-Lit. The Teaching Environmental Sustainability—Model My Watershed (TES-MMW) middle school curriculum is a data-rich MWEE that promotes student analysis of local watersheds. This large-scale study was conducted in eight states across the United States of America from 2016 to 2018, with data from 38 teachers and 1,263 students ages 11–18. The data shows a positive impact on students' E-Lit in watershed content and action. The study further suggests that four of the project's curricular elements were most influential in promoting environmental action for students. These curricular elements follow the MWEE framework, and as such, the MWEE essential elements are valuable guides in curricular design to support students' E-Lit development.

KEYWORDS
Data science; environmental education; GIS; modeling; outdoor learning; probe-ware; student use of technology

Introduction

The goal of the research presented in this article was to purposefully investigate the components of the curriculum that are likely to result in critical incidents, which are occasions that stay in mind and have a lasting impact on students that contribute to gains in E-Lit. The overall hypothesis is that students are more likely to develop an interest in watershed actions if provided with a curriculum that aligns with the Meaningful Watershed Educational Experience (MWEE) framework by providing them with experiences using real data, authentic geospatial analysis tools and models, and opportunities to collect supporting data. This approach embraces the idea of engaging students in doing science (in this case, citizen science data collection of local watersheds and advanced geospatial analysis and comparisons of data), allowing students to link community-based practices to watershed management (Sobel, 2013; Zimmerman & Weible, 2017).

Environmental education involves the study of Earth's complex systems, the results of which are both personal and global. The National Academy of Engineering lists clean water as one of 14 "Grand Challenges" in urgent need of engineering solutions (Riley et al., 2011). Tackling this grand challenge requires informed decision-making leveraging advances in watershed knowledge from improved environmental monitoring, data analysis, and modeling. Data science is a powerful scientific tool for watershed study and action as past environmental data can be used to predict future environmental conditions.

CONTACT Nanette Marcum-Dietrich ndietrich@millersville.edu Millersville University of Pennsylvania, Millersville, PA 17551, USA.

Integrating data science into secondary students' study of the environment provides them with the tools to make informed decisions about the environment. Meaningful learning about our changing Earth requires a pedagogy that provides opportunities for learners to explore their impact on their local watershed as they harness the explanatory and predictive powers of data to inform personal and community action.

The research, instructional technology, curriculum, and professional development components of The Teaching Environmental Sustainability—Model My Watershed (TES-MMW) (NSF DRL-1417722, DRL-1417527, DRL-1418133) project focus on enhancing students' environmental systems thinking about watersheds, engaging in data collection and analysis, and developing geospatial literacy by introducing the crosscutting concepts embodied in content-rich, community-based environmental analyses (Gill et al., 2013). The project's research examines:

Research Question 1. Do curriculum and resources, models, and tools designed using field experimentation with probeware, national datasets, and a scientifically valid watershed modeling application increase students' knowledge of watershed content and actions, intention to act, and locus of control?

Research Question 2. What aspects of the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum serve as critical incidents for students leading to a personal interest in watershed action?

Thus, a purposeful investigation of the impact of the curriculum on student outcomes is needed to identify curricular components that are likely to result in critical incidents, which are occasions that stay in mind and have a lasting impact on students' E-Lit development.

Theoretical framework

Our research is grounded in a constructivist theoretical framework that supports interdisciplinary study and problem-based pedagogy, rooted in Vygotsky's (1978) sociocultural theory and Bandura's (1977) social learning theory, a phenomenon-based approach to teaching and learning that builds on the social construction of knowledge where students are viewed as active agents in their learning, agents that have the self-efficacy to pursue skills and knowledge, to obtain competencies for academic achievement and life skills. Learning is constructed through experiences where the learner must engage in sense-making using environmental data; this social construction of meaning further positions experiential community experiences as inherent to our awareness of our local environment.

For students to develop more connected, sophisticated, and systems-oriented ideas about water, instruction must embrace constructivist ideas about the learner's active role in sense-making about their environment. Nevertheless, compelling evidence suggests that students' conceptual understanding of scientific topics, including environmental topics, bears little impact on their actual decisions on real-world scientific issues (Akin & Sheufele, 2017; Allum et al., 2008). Connecting classroom learning to real-world issues requires the intentional application of constructivist learning theories to curricula design. Ewing and Mill (1994) explain, "If we are to work toward a 'functional environmental literacy' that includes the capacity to formulate positions on water issues in daily life, we must develop strategies to help students achieve a better understanding of how water transformations occur."

The Teaching Environmental Sustainability—Model My Watershed (TES-MMW) research project is funded by the USA's National Science Foundation. The project produced a curriculum constructed using the Meaningful Watershed Educational Experience (MWEE) framework, which promotes experiential, outdoor, science-based inquiries into environmental issues affecting students' local watersheds (Zint et al., 2014). MWEE's intentionally frame the content learning in the context of personal environmental action. According to the USA's National Oceanic and Atmospheric Administration (NOAA), MWEE's "are multi-stage activities that include learning both outdoors and inside the classroom, where students investigate topics both locally and globally that are of interest to them, learn they have control over the outcome of environmental issues, identify actions available to address these issues, and understand the value of those actions (NOAA—Bay Watershed Education and Training (B-WET) Program, 2017)." The MWEE framework includes four essential elements: "issue definition, outdoor field experience, synthesis and conclusions, and stewardship and action" (Sprague et al., 2018) (see Figure 1).

Figure 1. MWEE four essential elements.

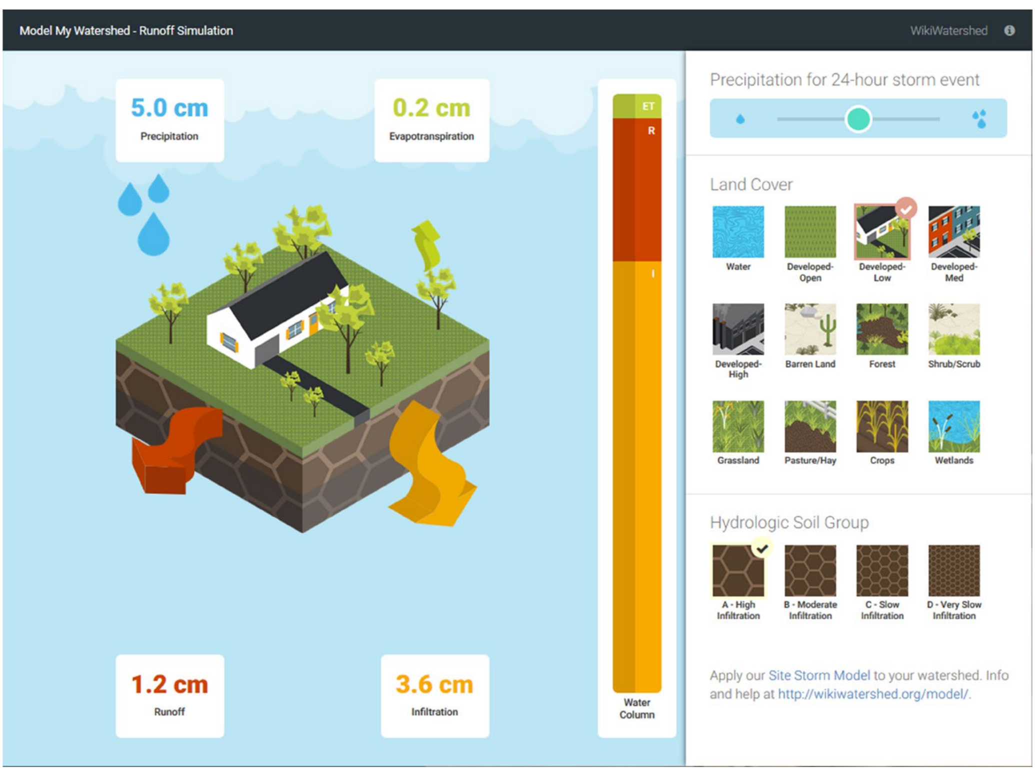

Figure 2. Example from the Runoff Simulation illustrating how water is distributed during a 24-hour rain event with the selected land cover and soil type.

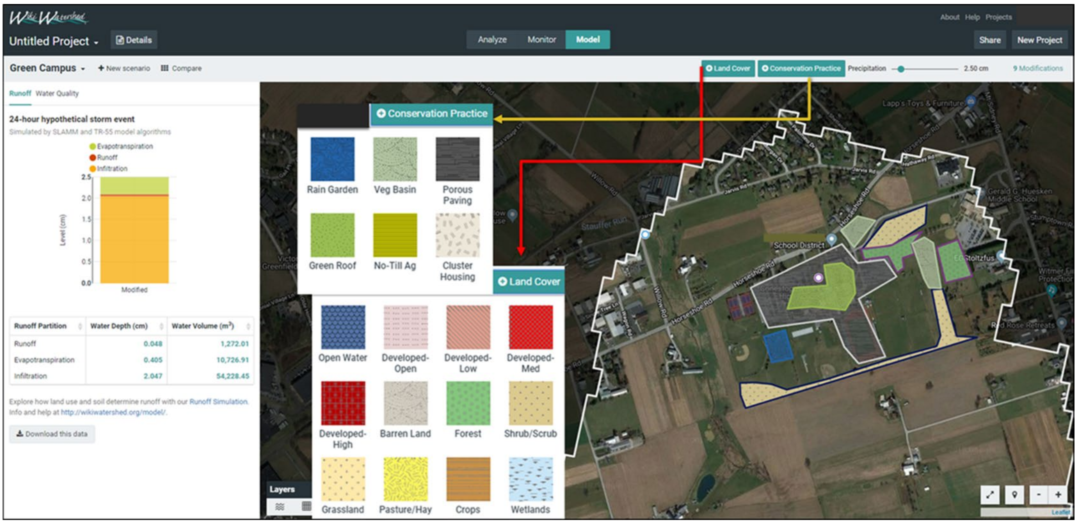

Figure 3. Example from a school Model My Watershed® GIS modeling project illustrating a scenario that includes proposed additions of conservation practices and land cover changes to improve the local watershed.

Based on the premise that this barrier between students' conceptual understandings of watershed content and their real-world actions can be bridged by the enactment of a constructivist curriculum that teaches watershed content using real data, scientific models, field study, and local places where students are challenged to make decisions about local watershed conditions, the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) project emphasizes scientific practices in the exploration of local watershed issues. These practices include: analyzing and interpreting data, using models, engaging in argument from evidence, and obtaining, evaluating, and communicating information (National Research Council (NRC), 2007).

Data science provides scientists with the quantitative tools to understand better the complex interactions between human activities and watershed health (Alilou et al., 2019), such as the link between land-use changes and groundwater quality (Narany et al., 2017), how upstream development impacts downstream flow patterns (Al-Faraj & Al-Dabbagh, 2015), and the impact of restoration activities on stream health (Lovette et al., 2018). Data modeling tools allow scientists to use metrics of watershed health, vulnerability, and recovery potential to establish protection and restoration priorities (Ahn & Kim, 2019; Lovette et al., 2018). Data provides the knowledge needed to inform environmental action by moving beyond school science to authentic learning about local watershed issues.

Results from our previous work (Gill et al., 2014; Gill et al., 2013; Marcum-Dietrich et al., 2015; Marcum-Dietrich & Staudt, 2017) suggests that using authentic local datasets to provide students with the ability to engage in environmental decision-making is an essential curricular design principle as most environmental challenges are complex and imbued with issues of potential social and economic conflict. To improve students' watershed understanding, curricula should be purposefully designed to provide students with meaningful opportunities to connect a conceptual understanding of watersheds to real-world decision-making (Ben-Zvi Assaraf & Orion, 2010; Ben-Zvi-Assaraf & Orion, 2005; Endreny, 2010; Gill et al., 2014; Gunckel et al., 2012). Understanding these curricula design choices and its' impact on students' E-Lit development informed the research questions in this study.

The teaching environmental Sustainability—Model My watershed (TES-MMW) curriculum

TES-MMW provided students with access to the same local and USA watershed data and scientific-grade computer models used by researchers and land-use planners. Using students' "home turf" as the object of exploration provides context and relevance to the data and models and thus may enhance engagement and better promote meaningful learning (Duffin et al., 2004; Semken & Freeman, 2008). Students analyzed real environmental data from USA federal databases, including the United States Geological Survey (USGS), the United States Department of Agriculture (USDA), NOAA, and other federal agencies embedded into the Model My Watershed® (MMW) GIS platform. Students in the study used MMW to model changes in land cover and conservation practices in the inquiry-based activities that included data students collected from their schoolyards using digital probes linked to tablets or smartphones (Windschitl, 2008). This curricular approach connects "school science" content to real-world applications by using authentic scientific data, knowledge, and practices to participate in evidence-based decision-making about issues impacting their local watersheds (Gunckel et al., 2012; Kali et al., 2003; Mohan & Boehm, 2009; Orion & Ault, 2007).

The curriculum was designed for Earth science and environmental science classes for students ages 11–18 and aligned with the USA's Next Generation Science Standards. Using a MWEE framework, the curriculum engaged students in an investigation of their local watershed using authentic scientific data. Data within the curriculum was localized, and the project's curriculum was customizable by teachers to their location. Teachers could add, delete, expand, reorder, and modify the activities to tailor them to students' abilities and prior knowledge and their school context while staying true to the goals and learning objectives. Teacher customizations ranged from simply replacing images in the activities with images from their schoolyard or community to bookending the unit with supplemental activities for building foundational knowledge or extending it with enrichment activities. Some teachers also modified explanatory text to classroom reading abilities for English language learners.

Issue definition

Students began the unit by exploring their watershed using Model My Watershed®, an online GIS software, and through a guided walking tour of their schoolyard. During the tour of the schoolyard, the teacher focused student attention on watershed features and issues that may have been previously invisible to students because they had not looked at their schoolyard from a watershed perspective. Students used a map from the GIS software to locate watershed features and issues. In the second activity, students learned about conservation practices, also known as best management practices, that could improve the health of their local watershed.

Outdoor field experience

In the third activity, students went back outside to collect environmental data using probeware, and they compared data from an area with an existing conservation practice to an area they believe needs a conservation practice.

Synthesis and conclusions

In the fourth activity, students used the online Runoff Simulation, a scaffolded learning tool, which is a simplified representation of the 24-hour storm event model in the Model My Watershed® online GIS software. In the Runoff Simulation, students changed both land cover (USGS land cover designations) and hydrologic soil groups (USDA) during different sized storm events to determine the amount of evapotranspiration, infiltration, and runoff for an imagined parcel of land.

Stewardship and civic action

In the culminating activity, students re-designed the schoolyard using their knowledge of what land features contributed to a healthy watershed via the Model My Watershed® GIS software. Students used this professional scientific-grade online software to access USA environmental datasets, select and analyze data for their schoolyard, and create and model scenarios in which they try to increase the amount of infiltration and improve the water quality at their school study site. Students modeled changes to land cover and installation of conservation practices, such as proposing reforesting part of the property, installing a green roof on part of their school, or constructing rain gardens in their schoolyard next to parking lots. Students then also compared outcomes of different scenarios side-by-side.

Research design

The study used a mixed-method design that involved the simultaneous collection and analysis of quantitative and qualitative data (Creswell, 2013) to answer the research questions more thoroughly. 38 Teachers were recruited from eight states across the USA. All students in the participating classrooms completed the curriculum. Data analysis was performed on data from students who, along with their guardians, granted permission for their data to be used in the research. The study occurred during three USA school years from 2016 to 2018. Pre- and post-test data were analyzed from 1,263 students. Students who indicated an actionable plan to improve a local watershed issue were identified using post-test data analysis for follow-up interviews/focus groups. Of 1,263 students, 464 (36.74%) presented a detailed plan to improve their local watershed or described a watershed action they have already completed and were identified as potential interview subjects. 116 (25%) of this sub-group were randomly selected for a follow-up interview, and 107 students agreed to be interviewed. Forty-one students participated in individual interviews, and an additional 66 students comprised 14 focus groups. (Focus groups were conducted when more than one student in a school was selected for a follow-up interview; this was done to minimize the disruption to the classroom.) The same semi-structured interview protocol was used for both the interviews and the focus groups. The research team that conducted this study was not the curriculum developers, and they remained independent of the curriculum design process and the student outcomes.

The instruments used in this study included: a 15-question watershed content knowledge assessment developed by watershed experts at Stroud Water Research Center, Inc., portions of the NOAA B-WET Secondary Science Self Report (Knowledge of Actions, Intention to Act, and Locus of Control), and a semi-structured critical incident technique (CIT) interview protocol that was developed by the research team to assess students' engagement and action. The watershed content knowledge and NOAA B-WET items were administered online as a pre-and post-test and analyzed using SPSS and Stata software to understand better students' changes in four environmental stewardship characteristics: 1. Watershed Content Knowledge, 2. Knowledge of Actions, 3. Intention to Act, and 4. Locus of Control (a feeling that their actions can make a meaningful difference). The interviews and focus groups were conducted using a semi-structured interview protocol that adhered to the CIT methodology (Butterfield et al., 2005; Flanagan, 1954; Spencer-Oatey & Harsch, 2015) to assess students' engagement and actions and to investigate which research-based curriculum features are the most significant transformational elements.

Flanagan, (1954) defines the critical incident technique as "a set of procedures for collecting direct observations of human behavior in such a way as to facilitate their potential usefulness in solving practical problems and developing broad psychological principles" (p. 327). CIT is most useful when researchers aim to understand the details and impact of different interactional events on individuals and the strategies used to handle them (Spencer-Oatey & Harsch, 2015). Research by Flanagan, (1954) suggests that a critical incident (CI) is "any observable human activity that is sufficiently complete to permit inferences and predictions to be made about the person performing the act" (p. 327). The CI is a complex phenomenon that does not occur independently of the student, but in many cases is a change in perception and awareness that stimulated the student into action (Cope & Watts, 2000). By evaluating the curricular features that have the maximum impact, the project makes recommendations on how to replicate these outcomes in the design of other inquiry science curricula across science content areas, thereby guiding how to design science curricula better to engage students' interests and actions.

Results

The pre and post-data results were used to investigate the question, ***Does the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum increase students' knowledge of watershed content, knowledge of actions, and intention to act and their locus of control?***

See Table 1 for descriptive statistics for pre and post-test data.

Change over time from pre- to post-test for four environmental stewardship characteristics were analyzed using Hierarchical Linear Modeling (HLM) with students at level 1 nested in schools at level 2. Hierarchical models were implemented because the study data is hierarchically organized, with students nested within schools. A multilevel analysis more accurately estimates the effects of variables at different levels of hierarchy than other analytic methods.

HLM general equation:

Level 1—Individual students: (Test scores) = $\beta_{0j} + \beta_{1j}$ (time) + r_{ij} (individual error)

Level 2—Schools: $\beta_0 = \gamma_{00} + \gamma_{01}$ (School) + μ_0 (group error)

The HLM analysis of student data indicated that students who completed the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum increased significantly in two of the four measured environmental stewardship characteristics (Table 2). Separate models were run for each variable (watershed content knowledge, knowledge of action, intention to act, and locus of control). The models were run in Stata (version 14). The two characteristics with significant increases were watershed content knowledge and knowledge of actions. The Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum had a significant positive effect on students' watershed content knowledge ($\beta = 1.98$, $SE = 0.08$, $p < .001$, $CI_{.95} = 1.81$ to 2.14) and a positive effect on students' knowledge of actions ($\beta = 1.61$, $SE = 0.15$, $p < .001$, $CI_{.95} = 1.32$ to 1.90). Compared to pretest scores, post-test scores measuring students' watershed content knowledge increased by 1.98 points; on the knowledge of action, scores increased by 1.61 points, after accounting for the nested structure of the data. Intention to act and locus of control did not differ from pretest to post-test ($\beta = 0.05$, $SE = 0.13$, $p = .72$, $CI_{.95} = -0.20$ to 0.29 and $\beta = 0.06$, $SE = 0.13$, $p = .63$, $CI_{.95} = -0.19$ to 0.32, respectively).

To explore this question, ***What aspects of the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum serve as critical incidents for students leading to a personal interest in watershed action?*** Students responded to three open-ended questions on the post-test. The questions

Table 1. Means, standard deviations, and correlations.

Variable	M	SD	1	2	3	4	5	6	7
1. Content knowledge (Pre)	8.05	2.77							
2. Content knowledge (Post)	10.03	3.12	.53**						
3. Knowledge of action (Pre)	21.99	4.82	.11**	.06*					
4. Knowledge of action (Post)	23.55	4.84	.13**	.15**	.42**				
5. Intention to act (Pre)	15.60	3.97	−.03	−.03	.19**	.08**			
6. Intention to act (Post)	15.63	3.94	.02	.05	.13**	.16**	.36**		
7. Locus of control (Pre)	25.92	4.60	.21**	.15**	.45**	.31**	.16**	.08**	
8. Locus of control (Post)	25.97	4.90	.22**	.29**	.28**	.55**	.08**	.08**	.53**

Note: M and *SD* are used to represent mean and standard deviation, respectively.
* indicates $p < .05$.
** indicates $p < .01$.

Table 2. Results of the Hierarchical Linear Model Analysis (variable tested individually).

				95% confidence interval	
Variable	β_{1j} (time)	SE	p	Lower	Upper
Content knowledge	1.98	.08	< .001	1.81	2.14
Knowledge of actions	1.61	.15	< .001	1.32	1.90
Intention to act	.05	.13	.72	−.20	.29
Locus of control	.06	.13	.63	−.19	.32

Table 3. Coding schema for the analysis of student interviews and focus groups.

Predefined categories	**Node**	Sub node
Most impactful	Curricular experience	Curricular Portal (ITSI) Model My Watershed® Sensor Tag Walk around the schoolyard
Watershed engagement	Out of school experience Personal engagement Affiliation or group engagement School-sponsored engagement	
Actions to improve the watershed	Completed actions Proposed actions	
Design and test solutions	Using online tools Using personal observation Using probeware	
Explore the watershed	Online exploration Outdoor exploration	
Evaluate watershed	Using online tools Using personal observation Using stream testing Using probeware	
Suggestions for improvement		

asked students how they can improve the health of their watershed by describing a watershed action they have completed or a plan for a watershed action that they could complete in the future. Of 1,263 students, 464 (36.74%) presented a detailed plan to improve their local watershed or described a watershed action they have already completed. The most frequently mentioned proposed or completed watershed action was the installation of additional plants and rain gardens (287 students) and the installation of a rain barrel (80 students).

> "My neighborhood and I can build a rain garden at the end of our street and the street is slanted so all the runoff water runs down there then into the river. If we put a rain garden there we can stop all the trash that the water picks up on the way down to the river and we would have a healthy watershed if everyone helps out. Then all the water can just flow into the river and it will be clean for the fish and it will also be healthy for the plants and fish in the water and right on the bank of the water." Grade 7—Colorado

> "I planted a rain garden in my backyard. This reduces the amount of runoff and filters the rainwater." Grade 7—Missouri

> "At my house or in my neighborhood to improve the health of the watershed we put rain barrels around our house to collect rain and reduce runoff, then we use that water to water our gardens. We also don't use fertilizer at all. But we could also install green roofs." Grade 8—Kansas

> "I convinced my dad to install a rain barrel and a garden after I told my family what could be done to help our watershed." Grade 8—Pennsylvania

> "In my neighborhood, I advocated for rain gardens that drastically improved the integrity of the watershed." Grade 11- Kansas

Of the 464 students who presented a detailed plan for improving their local watershed or described a completed watershed action, 41 students were interviewed, and 14 focus groups were conducted (involving 66 students) using a semi-structured CIT interview protocol to assess students' engagement and actions.

Analysis of the interview and focus group data began using an *a priori* coding process, in which the high-level categories are established before the analysis based upon established constructs articulated in the CI methodology (Blair, 2015).

A sample of interviews and focus groups were coded using the predefined categories to assess the credibility of the categories and to establish inter-coder agreement and interpretive convergence—the percentage at which different coders agree and the assignment of a particular code to particular data remain consistent—following Andersson and Nilsson, (1964) well-accepted guideline of 80% or better match rate for this credibility check. The coding process then proceeded in a manner that permitted the data to be further "segregated, grouped, regrouped, and relinked to consolidate meaning and explanation" (Grbich, 2007, p. 21) to search for patterns in data that have explanatory power (Bernard, 2011).

As stated previously, the pre-and post-test data reveals statistically significant growth in two of the environmental stewardship characteristics. Students' watershed content understanding and knowledge of action increased while their locus of control and intent to act remained unchanged. The interview and focus group data support these results. Of the 55 interviews and focus groups, 52/55 (95%) articulated a detailed personal plan for improving their local watershed, while only 18/55 (33%) of the interviews and focus groups included descriptions of completed watershed actions. When students completed an environmental action, the completion of the plan was most often facilitated through personal initiative 25/55 (45%) School-sponsored activities 20/55 (37%), and affiliation with community groups also identified as facilitating students to act 10/55 (18%), such as scouting, 4-H, and community environmental groups. See Figure 4.

To better understand which of the Teaching Environmental Sustainability—Model My Watershed (TES-MMW)'s curriculum components were most influential to students' engagement in watershed actions, students were asked to reflect on their experience with the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum and to describe which activities were most impactful

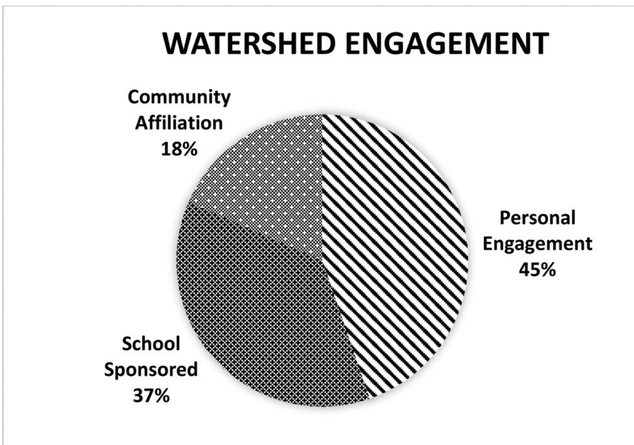

Figure 4. Student watershed engagement activities.

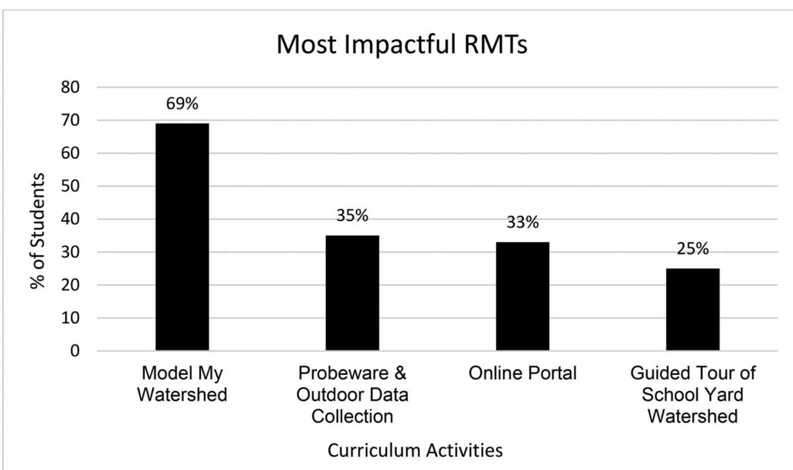

Figure 5. Curriculum activities that students reported to be most impactful and that motivated them to care about their local watershed.

and motivated them to care about their local watershed. Four curriculum components were frequently reported by students who were interviewed or who participated in a focus group: Model My Watershed® GIS application 38/55 (69%), Probeware and outdoor data collection 19/55 (35%), the Online Learning Portal 18/55 (33%), and the guided tour of the schoolyard watershed including use of a schoolyard satellite map 14/55 (25%).

Model My watershed®

"Model My Watershed, it was where we got to on the computer test it … see what kinds of different… like see if we had so much rain, see how the infiltration would change and if we change what kind of soil we had or if it was like a porous or any of that." Grade 7- Iowa

"My favorite activity was when we went on the website and got to change, and it had a little model that we could change what type of dirt and underground it was and what area it was, and we got to change the infiltration and such by changing the precipitation rate… I learned that when thinking of how to reduce runoff and stuff or how to build an area, you also have to put precipitation rates and such into the mix." Grade 7—Pennsylvania

Probeware and outdoor data collection

"Probably the going outside and doing the measurements because it was a pretty day and I enjoyed learning more and more about the watershed and how the different parts of the land just determine how the watershed can play out and why one spot is like there's no grass because of the water dripping—pouring down from the rain and stuff and funnels into the creeks." Grade 9—Virginia

"I liked the one where we got to go outside and we had to measure that square foot of land that was really fun and it was a great experience. I learned that there are different types of the soil and it determines where the water went or not because some of the soil was like sandy, some of it was clay. That was interesting." Grade 7—Iowa

Online portal

"The questions on the portal. I hadn't really thought about them before because in class we kind of were doing everything on our own for this it was kind of a chance to teach ourselves about the watershed by doing the tests that we were doing to seeing the questions that the website had for us was uhm definitely made us made me think more about the different test that we did." Grade 8—Pennsylvania

Walk around the schoolyard

"I liked walking around the school area and then like finding the downspouts and then looking at the conservation practices we already have and… checked… the vegetated infiltration garden and then we have a couple areas that are brick so it's porous and it can go into the ground to through that area." Grade 8—Kansas

Conclusion

Previous studies suggested that in the classroom setting, students typically make few connections between the content and their decisions (Raved & Ben Zvi Assaraf, 2011; Rose & Barton, 2012; Sadler, 2004; Zohar & Nemet, 2002), but this study's results provide evidence that MWEE aligned curricula help move students from isolated content learning to interest and knowledge to carry out civic and environmental action. The Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum effectively increased students' abilities in two of the environmental stewardship characteristics: content knowledge and knowledge of action. While students improved in their knowledge of actions they can take to improve their local environment, their locus of control and intent to act remained statistically unchanged. Even though the study did not find statistically significant changes in students' intent to act, 464/1,263 (36.74%) students did present detailed plans to improve their local watershed. Empowering students to believe that they can be part of the solution by changing their daily behavior is an essential element of teaching environmental sustainability (Hussein, 2018). This finding is noteworthy because the curriculum did not include a specific lesson that guided students through designing a plan of action or a requirement for them to complete an action (the only part of the curriculum that prompts students to take action is a brief description in an optional further investigation or final project for unit assessment at the end of the last lesson).

Identifying the specific curriculum components that promoted a CI for students is an essential outcome of the study as these findings have the potential to inform the design of future inquiry curricula across science content areas. The CI methodology used in this study which included 55 interviews/focus groups with 107 students, suggests that four of the curricular components in the MWEE aligned unit were most influential in promoting environmental action for students: Model My Watershed® GIS application 38/55 (69%), probeware and outdoor data collection 19/55 (35%), the online learning portal 18/55 (33%), and the guided tour of the schoolyard watershed including use of a schoolyard satellite map 14/55 (25%). The curriculum component identified as most influential by students was Model My Watershed®, a scientific-grade GIS modeling software that provides students with cognitive imagery that connects them to familiar places enhancing their understanding of watershed concepts (Ewing & Mills, 1994). This provides compelling evidence that students ages 11 to 18 can use a scientific grade modeling application that includes large-data sets & a computer model to identify actions that they as environmental stewards can take to impact the health of their local environment. Incorporating scientific-grade models, data collection tools, and a content-focused tour of the local environment are likely important curriculum design elements for promoting CI's via science instruction. Too often, school science only serves as a proxy or simplified facsimile of authentic science (Sobel, 2013; Zimmerman & Weible, 2017). This simplification and truncation of real-world science limit students' abilities to use scientific knowledge, practices, and data to learn about their environment as what they learn in the classroom may not be readily transferred to issues in their local environment.

Science instruction should help students see science as a set of practices that builds models to account for patterns of evidence in the natural world, and that helps students identify with local landscapes (Bizerril, 2004). What counts as evidence in science is contingent on making careful observations, collecting and analyzing real data, building arguments, and constructing models. If students can employ these scientific practices and use scientific-grade models and data, they will have greater success in building scientific literacy (National Research Council (NRC), 2007). Authenticity in scientific practice requires that students have access to the same resources, models, data, and tools as the science community.

Historically this effort toward authenticity was hampered by the complexity of large environmental datasets, little access to scientific-grade models, and the paucity of teacher training necessary to effectively use and to teach with scientific-grade models and data. Recent technical advances reduce many of these hurdles as costs have decreased, access to GIS technologies and models are now possible via web applications that reduce the complexity of data retrieval, presentation, and analysis. This project effectively connects school science content to the knowledge and practices of the scientific community (Gunckel et al., 2012; Kali et al., 2003; Mohan & Boehm, 2009; Orion & Ault, 2007). Capitalizing on the affordances of technological advances, the MWEE aligned Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum contains specific components, which upon study, provides evidence that students are capable of effectively using scientific-grade models and data in the classroom to build knowledge of watershed content and knowledge of actions they can take to improve their local environment.

Limitations

This study provides compelling evidence that students can participate in evidence-based decision-making about issues impacting their local watershed with access to scientific-grade data and models. However, the study is limited in its focus on the topic of watersheds for students ages 11 to 18. Additional research is needed in other science content areas and with other curricular components, beyond the four technology and data-driven components found to be influential for students in this study, to see if students are able to perform evidence-based decision-making about other scientific issues.

Suggestions for further research

Using scientific-grade data and models, students can learn watershed content and actions that can improve their watershed health, but the study did not find a statistically significant growth in students' locus of control (a feeling that their actions can make a meaningful difference) or their intent to act. This may be attributed to the lack of the inclusion of a lesson that guides students through creating and implementing a civic and environmental action plan in the Teaching Environmental Sustainability—Model My Watershed (TES-MMW) curriculum. While the project curriculum teaches students many different ways to improve the health of their watershed, knowledge of these actions may not be sufficient to prompt personal action.

The value of and the need to incorporate an action project in students' study of watersheds is identified as a need by NOAA's Bay Watershed Education and Training (B-WET) program. A civic and environmental action project is included as an essential element in B-WET's recently released- Meaningful Watershed Educational Experiences (MWEEs) curricular framework. MWEEs are "learner-centered experiences that focus on investigations into local environmental issues that lead to informed action and civic engagement" (Sprague et al., 2018, p. 4). Robust research on the effectiveness of the MWEE framework is needed to investigate whether the Stewardship and Civic Action phase of the MWEE is sufficient to positively impact students' locus of control and increase students' intent to act.

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ORCID

Nanette Marcum-Dietrich https://orcid.org/0000-0001-7535-3984
Carolyn Staudt https://orcid.org/0000-0002-0302-9082
Zachary Krauss https://orcid.org/0000-0003-2284-9454

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