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Case Study Article

Sea Grant Center for Great Lakes Literacy Shipboard Science Workshop Evaluation

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Abstract: Youth have an important role in current and future Great Lakes stewardship. Educating youth and empowering them to be Great Lakes stewards requires educators to be knowledgeable and confident, and therefore more likely to engage in teaching Great Lakes literacy activities in their classroom, thus contributing to a Great Lakes-literate public. The Shipboard Science Workshop (SSW) for educators is a vessel-based professional learning opportunity aboard the U.S. Environmental Protection Agency's research vessel (R/V) *Lake Guardian.* During the week-long SSW, educators learn from professional scientists, Sea Grant staff, and each other about Great Lakes research through the lenses of place-based education (PBE) and Next Generation Science Standards (NGSS). The goals of the SSW are to (1) enhance understanding of scientific concepts, processes, or techniques; (2) influence changes in teaching practices, curriculum, or personal behaviors; (3) influence communication and promotion of pro-environmental behaviors with others; and (4) establish communities of practice, including educators, scientists, and SSW coordinators. Herein, we present the findings of a 10-month follow-up survey to evaluate the SSW efficacy from 2016-2019. Overall, the SSW appears to have achieved its goals. We discuss the implications of these results within the PBE framework for shifting educators' classroom approaches and empowering youth inquiry and leadership on complex Great Lakes issues.

Keywords: *professional learning, place-based education, Next Generation Science Standards, communities of practice, social network analysis, vessel-based education*

The Laurentian Great Lakes, a significant feature in North America, contain approximately 20% of the world's fresh surface water, including 95% of the United States' surface water, and are an important component of the water cycle, water systems, and watersheds (Center for Great Lakes Literacy 2023). The Great Lakes suffer from impairments from aquatic non-indigenous species, ecosystem changes, non-point source water pollution, nutrients, emerging contaminants, and climate change, among others. Remediating and restoring the Great Lakes is considered a complex environmental problem, or a wicked problem, because of the interconnectedness of the source, problem, and solution (Rittell and Webber 1973). The Great Lakes Water Quality Agreement outlines the restoration and protection efforts on behalf of the United States with the Great Lakes Restoration Initiative (GLRI) and associated focus areas, themes, actions, funding, and interagency collaboration as the mechanism to achieve the goals for the Great Lakes (Great Lakes Restoration Initiative 2019). GLRI focus area 5 objective 1 specifically addresses the need to educate the next generation about the Great Lakes ecosystem with accurate information to make informed decisions regarding the Great Lakes and their watershed (GLRI 2019). Bridging the science and policy gap for effectively addressing these complex Great Lakes issues is needed, and

Research Implications

- Educators can learn approaches to teach science, Great Lakes literacy principles, and place-based education practices effectively.
- Youth can be engaged in meaningful watershed education experiences and empowered as informed problem-solvers for Great Lakes issues today and in the future.
- The R/V *Lake Guardian* Shipboard Science Workshop is a unique educator professional learning opportunity that inspires educators.
- Communities of practice, also known as networks for collective learners, enhance the capabilities for teaching Great Lakes literacy and empowering stewardship using place-based education (PBE) frameworks regionally and locally.

youth have an important role in that now and in the future (Krantzberg 2004; Great Lakes Stewardship Initiative 2017).

It is widely believed that elementary and secondary level teachers have the responsibility for developing environmental literacy in youth (Roth 1992). Integrating information on the Great Lakes into K-12 and nonformal teaching and learning settings is essential for a Great Lakes-literate society that: (1) understands principles and concepts about the characteristics, function, and value of the Great Lakes; (2) can communicate about the Great Lakes' influence on systems and beyond; and (3) is able to make informed decisions regarding the Great Lakes and their watersheds (CGLL 2023). With increased knowledge of the Great Lakes, and access to additional resources, educators can effectively incorporate Great Lakes literacy teaching and learning into their activities. The place-based education (PBE) framework is an established framework for facilitating youth learning and empowerment for problem-solving of complex Great Lakes issues, and has four main pillars: (1) set the focus; (2) establish foundations of place-based teaching and learning; (3) deepen impact; and (4) develop capacity for democratic participation (GLSI 2017). The Great Lakes Stewardship Initiative has championed PBE with schools and communities since 2007. These efforts established foundational case studies from across Michigan and contributed to the development of the aforementioned framework. The guiding principles for exemplary PBE inform the regional Center for Great Lakes Literacy (CGLL) approach (GLSI 2017). As an educational strategy for youth and community engagement, PBE has enhanced student learning and accomplished school improvement goals (Sobel 2004; Smith and Sobel 2010; Yoder 2012; Demarest 2015; Schroeder et. al. 2019). Similarly, PBE educational strategies can foster civic engagement values among youth committing to helping others, serving communities, and promoting understanding – i.e., they begin to believe that individuals do have the power to change society (Astin and Sax 1998; Gallay et al. 2016). As a result, youth engage in experiential learning and stewardship about the Great Lakes now and in the future.

Educators are a key partner for facilitating youth learning and empowerment for problem-solving of complex Great Lakes issues, and need professional learning opportunities with sustained support to adopt and implement PBE effectively. PBE reframes educators as student-centered learning process facilitators (i.e., guides on the side, rather than expert presenters), with relational support over time that results in adoption and transformation of teaching and learning practices, curriculum, and youth-community partnerships. As a result, educators facilitate learner-centered investigations of local environmental issues and student-led informed action, known as meaningful watershed educational experiences or MWEEs (National Oceanic and Atmospheric Administration Bay Watershed Education Training Program 2022). MWEEs include classroom and outdoor learning experiences that actively engage students in multi-disciplinary knowledge building and meaning making of the relationships between society and the natural world (NOAA BWET 2022). To facilitate relational support over time, educators are invited to join informal groups, known as communities of practice (COP), where people engage in collective learning along their professional learning journey (Wenger 2006).

We took a community-engaged research approach for this project, meaning we utilized foundational scholarship to inform evaluation

design and some research questions, and engaged with partners to identify their interests and needs in the research questions and design (Doberneck et al. 2017). Following the Next Generation Science Standards (NGSS) approach, our partners (i.e., Great Lakes Sea Grant Program co-leaders) were most interested in what core scientific ideas, practices, and cross-cutting concepts were learned and applied with students using a PBE framework because of the Shipboard Science Workshop (SSW) experience (Next Generation Science Standards 2023). NGSS is a transformational approach to science education because they describe science as both knowledge and a process of building, refining, revising, and extending knowledge (NGSS 2023). They include behaviors (i.e., practices) that scientists use within their fields, the interrelationships in different scientific fields and knowledge (i.e., crosscutting concepts), and core disciplinary ideas (i.e., core science) (NGSS 2023).

In this manuscript, we (1) describe the research vessel (R/V) *Lake Guardian* Shipboard Science Workshop (SSW), a nonformal Great Lakes vessel-based education program for adults who may be formal or nonformal educators to learn about the Great Lakes and PBE (Williamson and Dann 1999); (2) evaluate the SSW at achieving its goals (Williamson and Dann 1999); and (3) discuss SSW as a PBE professional learning opportunity for enhancing teaching, learning, and curriculum, all necessary for increasing Great Lakes literacy and effective decision-making (Dann and Schroeder 2015; GLRI 2019).

Program Description

The Sea Grant CGLL hosts the SSW, a professional learning opportunity for educators to spend one week working and learning alongside scientists aboard the United States Environmental Protection Agency's (U.S. EPA) R/V *Lake Guardian* (CGLL 2023). The R/V *Lake Guardian* cruises a different Great Lake each year, with the Sea Grant program associated with the lake coordinating the SSW. Extension and education professionals from the seven respective Great Lakes Sea Grant Programs collaborate with the U.S. EPA on workshop planning, implementation, and evaluation. To date, approximately 225 educators and nearly 50 scientists and others have participated in the R/V *Lake Guardian* SSW since its inception in 2006 (K. Tepas, personal communication, February 10, 2023).

Aboard the R/V *Lake Guardian*, educators learn from professional scientists from federal or state agencies, universities, and Sea Grant programs, about science topics such as ecology, geology, geography, biogeochemistry, and weather, while learning about real-world Great Lakes issues. SSW participants also learn about the Great Lakes literacy principles (Table 1), modeled after the ocean literacy principles (Fortner and Manzo 2011). The SSW goals are to: (1) enhance understanding of scientific concepts, processes, or techniques; (2) influence changes in teaching practices, curriculum, or personal behaviors: (3) influence pro-environmental behavioral intentions and behaviors, including communication with others; and (4) establish communities of practice, including educators, scientists, and SSW coordinators. The desired outcomes from SSW participation are to enhance educators' capabilities for teaching Great Lakes science and to inspire stewardship of the Great Lakes using PBE and MWEE frameworks.

Interested educators (i.e., formal and nonformal) are invited to apply to participate in the SSW, with typically 15 participating in each research cruise per year. The application process includes personal and professional contact information, fields of teaching certification/licensure, years of experience, subjects and grade levels of audiences, work demographics (e.g., number of learners, percentages of students who are English language learners, percentage of free or reduced lunch, diversity of school population), personal statement, and name and email address of person providing a letter of recommendation. There is no cost to participate in the SSW. Upon completion of the SSW, participants receive a certificate of completion for professional development contact hours. Through a partnership with Ashland University, participants can apply for two graduate credits for an additional fee of $370. Currently, participating educators are eligible for a $500 stipend upon completion of the SSW requirements and support of up to $250 to offset travel expenses.

Table 1. Great Lakes Literacy principles (CGLL 2023).

Number	Principle
1	The Great Lakes, bodies of fresh water with many features, are connected to each other and to the world ocean.
2	Natural forces formed the Great Lakes; the lakes continue to shape the features of their watershed.
3	The Great Lakes influence local and regional weather and climate.
4	Water makes Earth habitable; fresh water sustains life on land.
5	The Great Lakes support a broad diversity of life and ecosystems.
6	The Great Lakes and humans in their watersheds are inextricably interconnected.
7	Much remains to be learned about the Great Lakes.
8	The Great Lakes are socially, economically, and environmentally significant to the region, the nation, and the planet.

In addition to adhering to safety protocols, SSW requirements include: (1) completing a pre-survey, a post-survey, an end of year survey, and pre-trip assignments; (2) participating in two SSW-related virtual meetings; (3) leading Great Lakes curriculum initiatives, field-based or laboratory scientific activities; and (4) sharing research and experiences with public audiences, classrooms or programs, professional association meetings, or other audiences.

Methods

We implemented a long-term post evaluation survey that consisted of 11 open-ended questions (Patton 2002). We utilized a modified tailored design method and emailed up to four invitations to complete an online survey (Appendix A) approximately 10 months after participating in the SSW occurring 2016-2019 (Dillman, Smyth, and Christian 2009). The Michigan State University Institutional Review Board reviewed and approved of the project on August 15, 2016 (# x16-1011e Category: Exempt 2).

To evaluate an enhanced understanding of scientific concepts, processes, or techniques, we asked open-ended questions about their teaching, curriculum, and communication as a result of SSW participation. The survey also asked about changes in pro-environmental behavioral intentions and behaviors, including communication with others (e.g., scientists and educators who were not part of the SSW), and any other comments about personal or professional activities or impacts stemming from their experience. The qualitative response data to open-ended questions were grouped by common themes (Rubin and Rubin 2005). This could be a common change in behavior, a specific scientific process, or post-SSW action taken. Those themes with the highest frequencies were summarized as main lessons for that particular year.

To assess the establishment of post-SSW COPs, we asked respondents to identify up to ten educators who participated in the SSW, up to three scientists, and up to three staff coordinators they have had contact with since participating in the SSW. Social network theory and analyses were used to reveal the extent of relationships among participants, indicators of established COPs. We used Ucinet 6 for Windows (version 6.620) (Muhr 2009) for social network analysis, which consisted of centrality calculations and netdraw sociograms. We calculated four centrality measures: (1) betweenness centrality, a measure of the extent to which a network actor (e.g., node) is in-between all other nodes influencing the entire network; (2) closeness centrality, a measure of the extent to which a node is near all other nodes directly influencing others in the network; (3) degree centrality, a measure of how many neighbor nodes a node

has to influence; and (4) eigenvector centrality, a ranking measure of the number of connections a node has relative to other nodes influencing other nodes in the network (Scott 2000).

Results

Fifty-nine educators participated in the R/V *Lake Guardian* SSW from 2016 to 2019. Twenty-five completed the 10-month follow-up survey for a 42% response rate. Because survey respondents could identify individuals from the SSW that did not respond to the survey, network sociograms of post-SSW COPs included 51 educators, 12 scientists, and 7 SSW coordinators across all years. Of the eight Great Lakes literacy principles (CGLL 2023), our qualitative survey research appears to have covered all but principle two (natural forces formed the Great Lakes; the lakes continue to share the features of their watershed). Table 2 is a summary of the key themes from the qualitative analysis and trends across 2016-2019. Table 3 is a summary of the network descriptions and key roles in COPs.

Enhanced Understanding of Scientific Concepts, Processes, or Techniques

A variety of major scientific concepts were mentioned following SSW participation. These included basic ecological knowledge such as food webs, lake stratification, lake ecology, and identification of fish species (principle five; CGLL 2023). Scientific processes learned during the SSW centered around sampling methods, utilization of scientific methods, data collection protocols, instruments, and scientific resources, with survey respondents reporting gaining knowledge in these areas as a result of participation. When it came to water quality monitoring, respondents reflected on the importance of data and its impact on real world applications (principle seven; CGLL 2023). They were particularly impressed with the sampling equipment aboard the R/V *Lake Guardian*, such as the Rosette water sampler, and expressed excitement upon seeing it in action. This exposure to scientific methods and sampling practices resulted in respondents expressing increased confidence using scientific equipment.

Inspiring Place-based Education Approaches to Great Lakes Literacy, including Changes in Curriculum and Practices

This opportunity also impacted those who were shifting in their field of expertise, introducing them to environmental concepts with which they were unfamiliar.

> *"My background is in engineering and design of avionics displays and systems before I became a science teacher. My traditional affinity has been toward the physical sciences, with little personal interest in bio sciences. However, since I am now responsible for several life sciences/ bio courses I wanted to learn more about these areas from people who had made it their passion (so I could "catch" their excitement to transfer that to my students). The … Shipboard Science Workshop was just the solution to helping me become passionate about teaching about living organisms and biological science. I am a better life science and biology teacher because of my experience on the* [R/V] *Lake Guardian..."*

For others, the content of the SSW revitalized their love of teaching, created excitement, and inspired new ideas for their classroom lessons. The opportunity to see scientific principles in action, and to work with, as one respondent put it, "world famous scientists" in a field setting left a lasting impact on several of the SSW participants. In the words of one participant:

> *"The Shipboard Science Workshop on the Lake Guardian is truly a unique experience. It allowed the scientist in me as an educator to flourish and grow. It challenged me to dig in and learn, explore, and be inquisitive to gain depth of knowledge on a topic that is extremely important to me as well as my community. At the same time the experience gave me resources to bring back to my classroom to use and share with my students. I definitely will continue to take advantage of any opportunities* [to] *gain more understanding and knowledge of the Great Lakes to share with my students and my community."*

There were also personal changes in regards to water and Great Lakes knowledge, with one participant altering their assumptions when it came

Table 2. Thematic summary from R/V *Lake Guardian* Shipboard Science Workshops, 2016-2019.

Survey Question Topic	Key Takeaways	Year(s) Reported
Major scientific concept learned	Harmful algal blooms	2016, 2018, 2019
	Water contaminants/microplastics	2018, 2019
	Role of food webs/importance of zooplankton	2016, 2017
	Lake stratification	2016, 2017
Major scientific process or techniques learned	Scientific equipment usage	2016, 2017, 2018, 2019
	Scientific data collection/techniques/protocols	2016, 2017, 2019
Changes in teaching practices or curriculum enhancements	Information integration into classroom lessons/ curricula	2016, 2018, 2019
	Supplemental knowledge/information expansion	2016, 2017, 2018
	Environmental field trip planning	2016, 2017, 2018, 2019
Changes in personal behaviors	Reduction/elimination of single-use plastics	2016, 2017, 2018, 2019
	Invasive species awareness	2016, 2017, 2019
Contexts where participant encouraged others to adopt pro-environmental personal behaviors	Reduction of plastic usage	2016, 2017, 2019
	Encourage sustainable environmental practices (picking up debris, avoid unnecessary buying, reusable water bottles, etc.)	2016, 2019
Communication about R/V *Lake Guardian* SSW with non-scientists or educators	Discussed with colleagues	2016, 2019
	Presented to other educators/school board/ conferences/etc.	2016, 2018
	New collaborations with other educators	2016, 2017
Personal or professional impacts or experiences	Wonderful, unique, memorable experience	2016, 2017, 2019
	Inspiring and motivating	2016, 2018, 2019
	Appreciation for networking opportunities	2016, 2018, 2019

to their classes' knowledge on these subjects and no longer presumed their students had a baseline knowledge simply from growing up in the Great Lakes region. Another reflected on the fact that the lessons presented gave her the ability to let her students have more autonomy over their learning and reminded her of what it was like to be a student herself.

Respondents also reported that they were inspired to become more involved in their communities. By participating in the R/V *Lake Guardian* SSW, some survey respondents reported that they were better able to educate others, both personally and professionally, about the work being done by scientists in the Great Lakes, and to use their knowledge to impact the next generation. Overall, respondents indicated positive and unique experiences for participating educators that left a lasting impact on their personal and professional philosophies about science education. In addition,

Table 3. Social network sociogram summary, R/V *Lake Guardian* Shipboard Science Workshops, 2016-2019.

Dimensions	2016	2017	2018	2019
# Educators	16	11	10	14
# Scientists	6	2	3	1
# CGLL staff	2	2	2	4
Total actors	24	15	15	19
Actor with highest betweenness centrality score	Educator #2	Educator #2	Educator #5	Educator #1
Actor(s) with highest closeness centrality score	Educator #15	Scientists #24 & #25	Scientist #26	Educator #15
Actor with highest degree centrality score	Educator #10	Educator #2	Educator #6	Educator #1
Actor with highest Eigenvector centrality score	Educator #10	Educator #2	Educator #6	Educator #1

the lessons learned aboard the R/V *Lake Guardian* assisted some in professional development. Participants expressed a greater understanding of Great Lakes literacy and for one, the knowledge gained assisted them in completing an educational certificate.

The SSW experience provided more real-world examples they could share with their classes, while others mentioned that they gained a much greater depth of understanding of Great Lakes issues, affecting their lesson planning as a result. Specifically, Great Lakes lessons such as place-based information, proper data collection techniques, information on water contaminants like perfluorooctane sulfonic acid (PFOS), and water quality principles were added to teachers' units and lessons. Exposure to scientific concepts and sampling techniques resulted in respondents expressing increased confidence using data collection equipment and utilizing some of the instrumentation within their classrooms, such as incorporating water and macroinvertebrate sampling or microscope usage into their lessons.

Several participants reported creating lessons around the impacts of coastal storms and the effects of climate change, water contamination, invasive species, and knowledge of water contaminant issues and the impacts of harmful algal blooms and microplastics (principles three, five, and six; CGLL 2023). Another respondent reported that they began including fish dissections in their classroom lessons following SSW participation, in order to incorporate a hands-on element to their lessons (principle seven; CGLL 2023). One individual reported borrowing a deployable freshwater sensor (e.g., Hydrolab) for their students to take water quality measurements around their community. As a result of SSW participation, teachers guided their students in collecting and analyzing real world data in their own communities, making the scientific processes learned during the SSW locally relatable (principle six; CGLL 2023). One participant also planned a field trip for their class to The Ohio State University's Stone Lab as a result of SSW participation. Another reached out to a local university to help fully immerse their students in their annual field trip to the beach to collect water samples by providing an excursion on Lake Michigan. Survey responses also indicated an increased awareness of Great Lakes stewardship and local water issues and a greater confidence in their ability to communicate those issues to their students, engaging students and fostering a greater sense of stewardship for both their local resources as well as those of the larger Great Lakes basin.

Information gained as part of the SSW extended beyond formal classroom lessons as well. One respondent described the development of a student-run education program focused on Great Lakes invasive species based on the Attack Pack, an

aquatic invasive species education kit developed by Sea Grant CGLL they were introduced to during the SSW. Another respondent indicated one of their 8th grade students was so inspired by the knowledge that was shared in the classroom regarding macroinvertebrates they did their own research project on the health of their local rivers, making it into their science project for that year. In addition, resources such as videos of the shrinking cups activity from the SSW and U.S. EPA data records were incorporated in order to supplement classroom lessons. Another respondent reported they conducted a "microplastic sweep" of their schoolyard following their participation on the SSW, removing several pounds of "tiny plastics from their school-yard ecosystem."

Changes in Pro-environmental Behavioral Intentions and Behaviors, including Communication with Others

Overall, changes in pro-environmental behavioral intentions were related to invasive species. Respondents described a desire to adopt behaviors that would reduce the spread of invasive species as well as prioritizing the use of native plant species, stewardship, and increasing the awareness of the impacts of invasive species. Changes in personal behaviors fell into one of two categories: reduction of water contaminants and increased awareness. Specifically, changes in behaviors focused on reducing plastic waste and preventing environmental contamination, including reducing the use of single-use plastics and avoiding purchasing products with plastic microbeads. Respondents mentioned encouraging the use of reusable water bottles and leading by example by limiting plastic product usage in both personal and professional settings. Proper disposal of items harmful to water quality was also discussed, including both living (aquarium plants) and non-living (medications, harmful soaps and chemicals) items.

Other respondents brought their pro-environmental behaviors into their schools by producing public service announcement (PSA) style videos with their class on Great Lakes issues, encouraging their students to attend local environmental talks with their families for extra credit, encouraging the use of water quality nutrient issues for science fair projects, or by teaching their students the value of seeing the system as a whole, that all of these issues are interconnected and impact the greater environmental system (principles one and eight; CGLL 2023). A common theme was leading by example. By performing pro-environmental behaviors themselves (e.g., using reusable water bottles, using metal straws, picking up debris while outdoors) and then discussing them with their students, participants were able to open a dialogue about shared interests and environmental behaviors. There was also strong support of the Great Lakes and an awareness of Great Lakes issues, specifically at the policy level. One respondent indicated that they would be proactive, contacting their state leaders to ensure that Great Lakes issues remained forefront in budget discussions. Some took this conscientious behavior a step further, applying these changes to their school by introducing recycling programs or becoming involved in their local conservation programs. Another respondent reported the increased awareness of plastics in the Great Lakes as a result of the SSW which led to contributing to a local watershed group to support their activities. Being good environmental stewards by using chemicals like fertilizers responsibly was also mentioned.

Several respondents reported that they shared their experiences with other educators who did not participate in the SSW. These efforts included presentations, curriculum development, other workshops, sharing photos through social media, and sharing SSW resources through shared workspaces like Google Drive. Survey respondents reported sharing their knowledge with not only their students, but with fellow teachers, and utilized several of the activities they took part in aboard the SSW in order to do so, such as the shrunken cup activity demonstrated while on board. Responses indicated presenting as part of several major organizations and conferences such as the National Science Teachers Association, The Association for the Advancement of Sustainability in Higher Education conference, the Master Teachers program, and the Math and Science Workshop at the State University of New York Plattsburgh. Respondents also encouraged fellow educators to participate in the SSW by both collaborating on projects and sharing with individual departments.

At least one respondent participated in a future workshop as a result of these efforts, according to survey responses. Respondents described contacts and collaborations they initiated with water research and conservation groups and programs as a result of participating in the SSW. The contacts included staff at Grand Valley State University Annis Water Resources Institute, Michigan Technological University Great Lakes Science Center, Save the River – St. Lawrence, New York Department of Environmental Conservation, the University of Buffalo Great Lakes Program, and the Milwaukee Metropolitan Sewage District.

Post-SSW Communities of Practice

Individuals with educator roles were at the center of the sociograms as indicated by the betweenness centrality measures (Figure 1) and closeness centrality (Figure 2; Table 3). Therefore, they have the greatest opportunity to influence the entire network and all individuals within the network with the information they share. Similarly, individuals with educator roles also had the highest degree centrality scores (Figure 3; Table 3) meaning that they have close neighbor actors that they can influence. Except for 2019 (Figure 4d; Table 3), scientists were on the periphery of the network sociograms as indicated by closeness centrality, meaning that they have greater opportunity to directly influence others (i.e., SSW coordinators and educators) in the network. Individuals with an educator role had the highest eigenvector centrality scores (Figure 4), meaning that educators ranked highest of most network connections relative to other actors in the network. Much of the interaction described by respondents identified social media and other digital means of communication (e.g., Google Drive, email, etc.) as the primary method of connecting, communicating, and sharing resources. Facebook appeared to be the most prominent mechanism for educators; however, this may not be the most likely way scientists communicate with others.

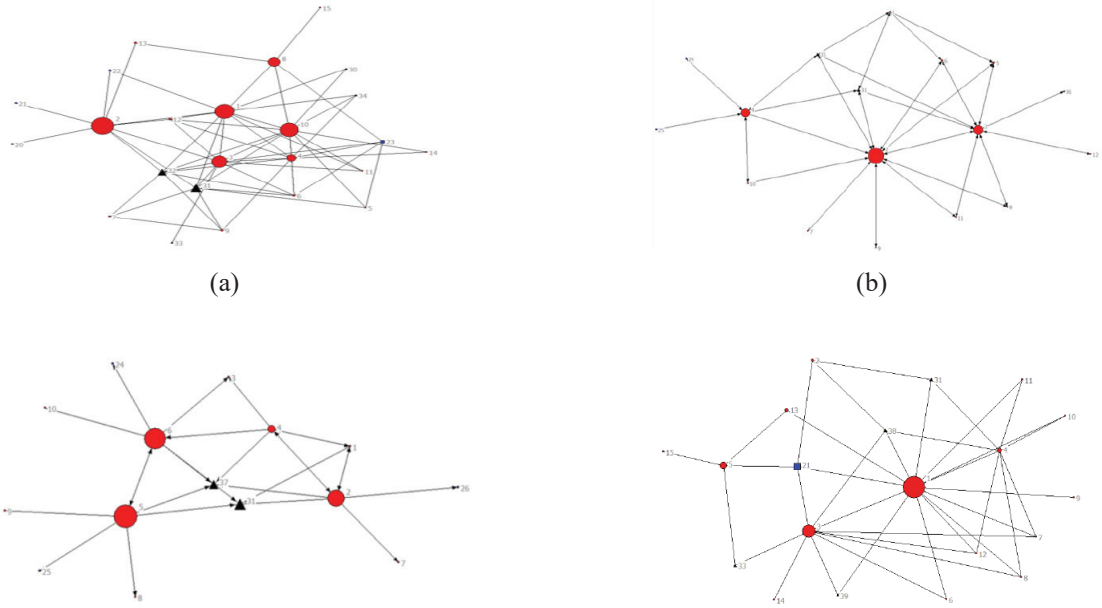
Overall, SSW respondents shared positive comments about their experience. Individuals characterized the SSW as "memorable," "unique," and "wonderful" among others. Many gained motivation and inspiration for their teaching, giving them new perspectives or new tools to incorporate into classroom lessons. The opportunity to network with like-minded educators from around the state, as well as to connect with scientific professionals, was also noted highly. This experience was mentioned by several to have made a significant impact on them, both personally and professionally. They valued the friendships found in a group of like-minded teachers that shared some of the same interests. These sentiments were aptly summarized in the comment made by one respondent:

> *"Having the opportunity to participate as an educator in the* [R/V] *Lake Guardian Shipboard Science Workshop was one of the most memorable professional and personal experiences of my life. I absolutely loved being on board the ship and conducting research with other educators from around this part of the country. I formed many lasting friendships and gained many new ideas for how to make learning engaging and fun for my students. This experience will be something that I carry with me throughout the rest of my life!"*

Discussion

Overall, we believe the R/V *Lake Guardian* SSW was an effective professional learning opportunity, achieving its goals to (1) enhance understanding of scientific concepts, processes, or techniques; (2) influence changes in teaching practices, curriculum, or personal behaviors; (3) influence pro-environmental behavioral intentions and behaviors, including communication with others; and (4) establish communities of practice, including educators, scientists, and SSW coordinators. We believe educators increased their knowledge and application of Great Lakes literacy principles and the PBE framework for empowering youth to solve complex environmental problems today and for the future. The most salient outcomes are (1) the shift in educators viewing themselves from expert instructor to student-centered learning process facilitator (i.e., educator is learning guide on the side), (2) educators' efforts to connect their classrooms to community through projects and field trips, and (3) self-reflections on how the experience inspired their love of teaching.

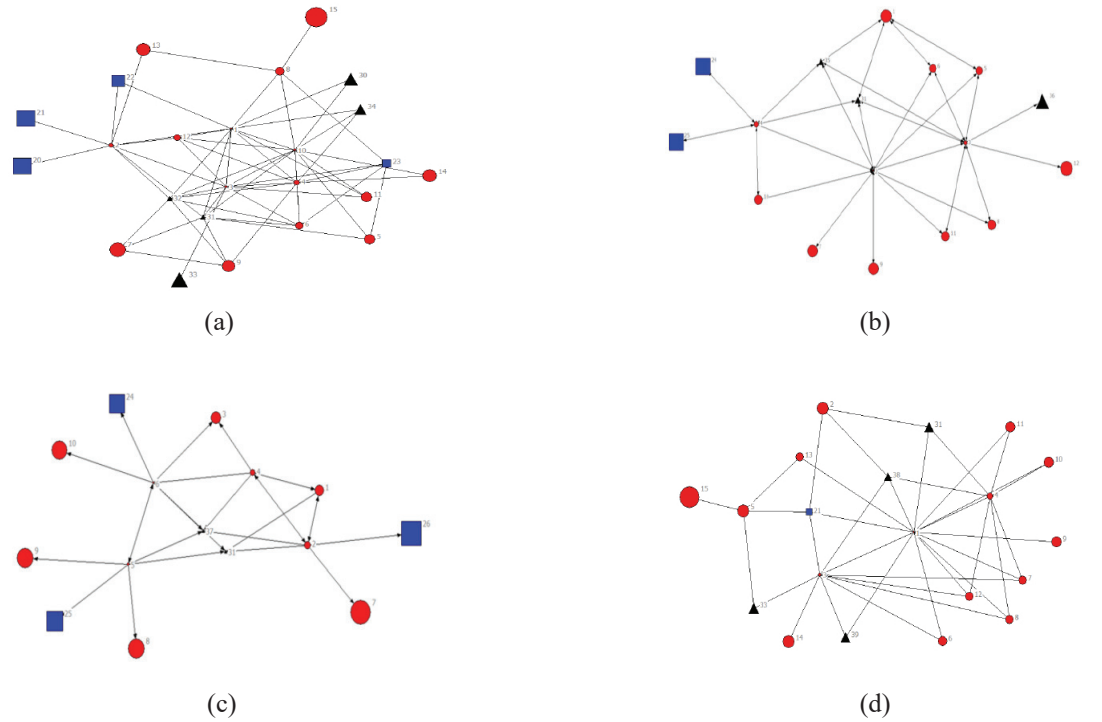
Using the PBE framework (GLSI 2017), the SSW *set the focus (PBE pillar I)* through a vessel-based



(a) (b)

(c) (d)

Figure 1. Community of practices network sociograms, all network actors: (a) 2016; (b) 2017; (c) 2018; (d) 2019. Red circles = educators; blue squares = scientists; black triangles = CGLL coordinators; size of node = betweenness centrality. R/V *Lake Guardian* Shipboard Science Workshops, 2016-2019.



(a) (b)

(c) (d)

Figure 2. Community of practices network sociograms, all network actors: (a) 2016; (b) 2017; (c) 2018; (d) 2019. Red circles = educators; blue squares = scientists; black triangles = CGLL coordinators; size of node = closeness centrality. R/V *Lake Guardian* Shipboard Science Workshops, 2016-2019.

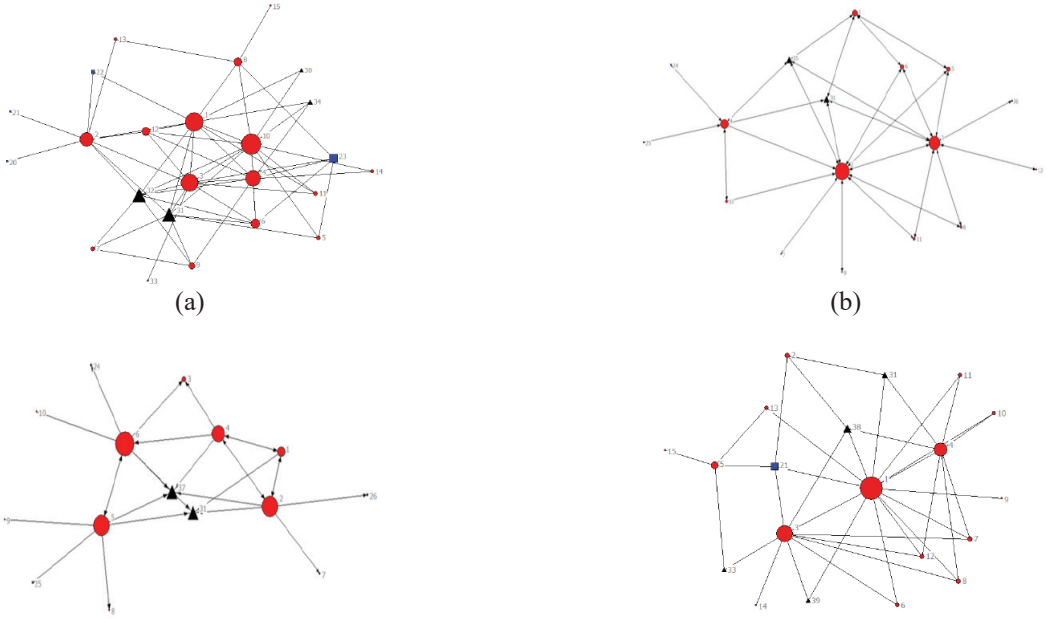


Figure 3. Community of practices network sociograms, all network actors: (a) 2016; (b) 2017; (c) 2018; (d) 2019. Red circles = educators; blue squares = scientists; black triangles = CGLL coordinators; size of node = degree centrality. R/V *Lake Guardian* Shipboard Science Workshops, 2016-2019.

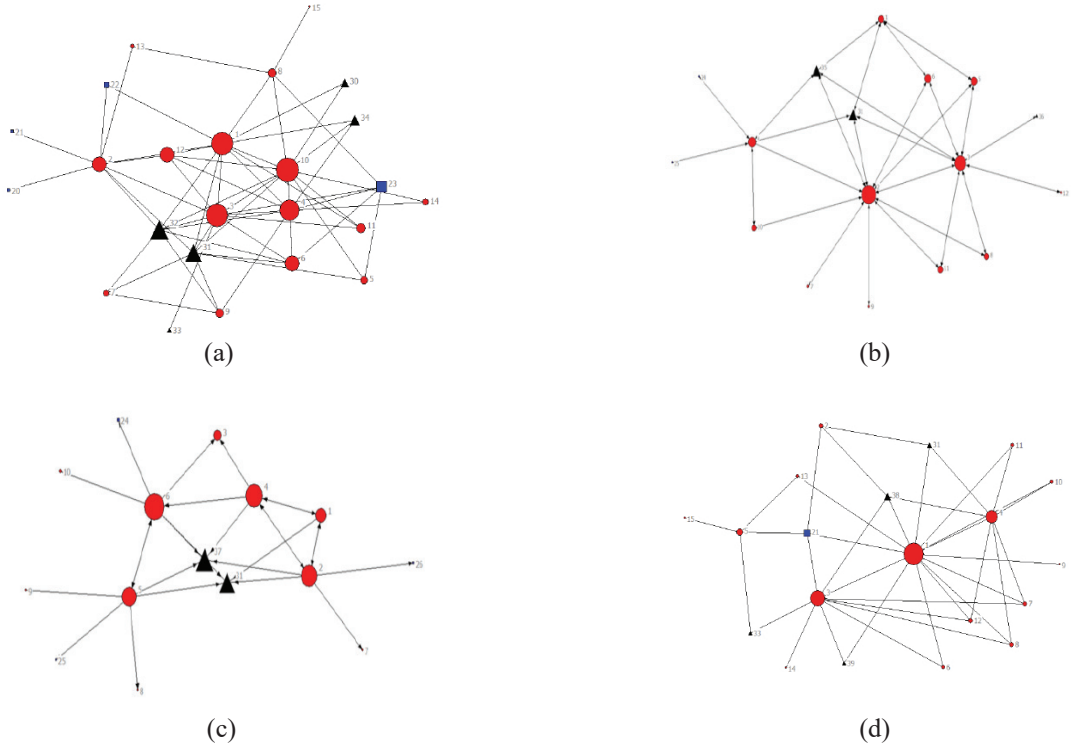


Figure 4. Community of practices network sociograms, all network actors: (a) 2016; (b) 2017; (c) 2018; (d) 2019. Red circles = educators; blue squares = scientists; black triangles = CGLL coordinators; size of node = eigenvector centrality. R/V *Lake Guardian* Shipboard Science Workshops, 2016-2019.

experience on the Great Lakes where participants learned about the context, including the Great Lakes literacy principles. This is also where they learned about scientific concepts, processes, or techniques, a key dimension of establishing a *foundation of PBE teaching and learning (PBE pillar II)*. While this evaluation demonstrates that overall, SSW participants learned scientific concepts, processes, and techniques, it did not examine progress toward specific Great Lakes Literacy principles or specific scientific dimensions. Future evaluation could address this research gap. Alternatively, future SSW planning could strategically evaluate which Great Lakes Literacy principles, as well as specific scientific concepts, processes, or techniques, are most transferable to teaching and learning settings, and therefore prioritize them in the SSW curriculum.

Educators are implementing curriculum enhancements that they made because of what was learned while participating in the SSW and their COPs. Most respondents shared that they incorporated much of the presented information into their lesson plans, including incorporating new scientific equipment usage or organizing field trips for their students like their own SSW experience. Frequent comments also indicated that the SSW experience solidified their commitment to the Great Lakes Literacy principles as well as inspiring them with renewed passion for their lessons.

Our 10-month follow-up survey reveals how SSW participants are *deepening impact (PBE pillar III)* through a variety of school-community partnerships, such as field trips to university laboratories or to visit a Great Lake. Consequently, educators' student-run Great Lakes education programs or specific environmental research topics are excellent examples of sustained inquiry into a local environmental issue. Similarly, respondents described students producing PSA-style videos on the Great Lakes and encouraging students to attend local environmental talks with their families, all examples of *PBE pillar IV (developing skills for participation in democratic practices)*. If specific pro-environmental behaviors are of interest (e.g., reduce single use plastics or reduce fertilizers), future SSW coordinators may want to incorporate specific examples into the learning experiences or provide tailored resources. Alternatively, highlighting examples of past participants, to provide relatable, real-world examples from those who have completed the SSW, may be an effective way to show participants how to implement the PBE approaches. Specifically, examples from student-led initiatives are now highlighted in a marine debris Great Lakes Literacy education exploration (Great Lakes Literacy education exploration 2023).

Finally, one of the tenets of SSW is to foster Great Lakes literacy by creating an engaged COP. Overall, our 10 months post-SSW evaluation reveals network connections among most participants, indicating an established COP. For the most part, educators serve in central roles, instead of SSW coordinators or scientists, indicating their ownership and potential influence on collective learning about the Great Lakes literacy principles and adoption of the PBE framework. Social media platforms such as Facebook or collaboration software such as Google are most often used by educators, therefore SSW coordinators may want to consider how to effectively use social media to connect with each other and to share educational resources. In contrast, scientists may not typically use Facebook or Google collaboration in their work. Therefore, SSW coordinators may need to be intentional about how they invite scientists to connect with or share resources with educators. In other words, post-SSW, educators appear to be off and running with self-organizing a COP, and SSW coordinators may need to check-in with them, see what needs or opportunities exist, and reach out or bridge to scientists and invite them to contribute to the COP as needed.

One research limitation was a somewhat low response rate (42%); additional efforts to reach participants may have been helpful at increasing the response rate. Alternatively, a study design that utilized participant interviews may have yielded a higher response rate. Another study limitation is that the questions were open-ended instead of including some Likert-type questions that invited participants to select response options that could be descriptively summarized or used in other analyses.

Finally, SSW program coordinators could redesign the SSW learning objectives by selecting

grade-level(s) to focus the NGSS instruction of practices, crosscutting concepts, and core scientific ideas covered and aligning to the CGLL principles and PBE pillars. If this occurs, future research could examine the extent to which educators implement NGSS and PBE approaches in their classrooms. Within the context of the CGLL principles (2023), PBE (GSLI 2017), and MWEE (NOAA BWET 2023) frameworks, effective incorporation of NGSS into classroom learning empowers students to act locally today, as well as continue a trajectory of developing human capacity to be part of a global twenty-first century. Future efficacy evaluation could document the student-led outputs and impacts and relate it to evaluation results from other PBE initiatives.

Conclusion

Our study reveals SSW is effective at enhancing understanding of scientific concepts, processes, or techniques, and had an impact on Great Lakes teaching and learning activities. Additionally, educators are implementing modifications to teaching and curriculum using the PBE approach through student-led, sustained inquiry and youth-community partnerships to empower students with voice and choice. Although SSW has many requirements, participation refreshes and inspires educators' love of teaching and capabilities for empowering youth to solve Great Lakes issues today and in the future. While not every educator can participate in this type of professional learning opportunity, through the resulting COPs, place-based networks and capabilities can grow locally.

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Appendix A. Sea Grant – Center for Great Lakes Literacy Lake Guardian Shipboard Science Workshops Evaluation Survey, 2016 – 2019

1. What is your name? *(Please type name in box below.)*
2. Please describe one major concept (e.g., aquatic invasive species, harmful algal blooms, lake stratification) you learned about or increased your previous knowledge about while participating in the Lake Guardian Shipboard Science Workshop. Tell us about one or two teaching and learning situations in which you effectively conveyed this to students, other teachers, school administrators, or others (e.g., family, friends, neighbors, or community partners). *(Please type one paragraph or less in box below.)*
3. Please name and describe one scientific process or technique (e.g., use of specific equipment, specific sampling technique, online data analysis program) you learned while participating in the Lake Guardian Shipboard Science Workshop. Tell us about any teaching and learning situations in which you effectively conveyed this to students, other teachers, school administrators, or others (e.g., family, friends, neighbors, or community partners). *(Please type one paragraph or less in box below.)*
4. Please describe any changes in teaching practices or curriculum enhancements you have adopted since participating in the Lake Guardian Shipboard Science Workshop (e.g., increased use of scientific inquiry, adding new Great Lakes-related units or stewardship projects) to support Great Lakes literacy. *(Please type one paragraph or less in box below.)*
5. Please describe any changes in personal behaviors you have adopted (e.g., limiting purchases of bottled water, limiting single-use plastic products, taking precautions to reduce spread of aquatic invasive species, reducing overuse of fertilizers) as a result of participating in the Lake Guardian Shipboard Science Workshop. *(Please type one paragraph or less in box below.)*

6. Please describe any contexts in which you have encouraged others to adopt personal behaviors (e.g., reducing overuse of fertilizers, limiting purchases of bottled water, limiting single-use plastic products, taking precautions to reduce spread of aquatic invasive species) that reduce impacts on the environment as a result of participating in the Lake Guardian Shipboard Science Workshop. *(Please type one paragraph or less in box below.)*
7. Please identify up to 10 educators who participated in the Lake Guardian Shipboard Science Workshop that you have contacted since your experience. Type each educator's name below and describe the type of interaction or request made of that educator (e.g., following on social media, sharing ideas or resources, collaborating on class projects or stewardship projects). *(Please type educators' names below.)*
    a. Educator 1 (name and describe interaction):
    b. Educator 2 (name and describe interaction):
    c. Educator 3 (name and describe interaction):
    d. Educator 4 (name and describe interaction):
    e. Educator 5 (name and describe interaction):
    f. Educator 6 (name and describe interaction):
    g. Educator 7 (name and describe interaction):
    h. Educator 8 (name and describe interaction):
    i. Educator 9 (name and describe interaction):
    j. Educator 10 (name and describe interaction):
8. Please identify up to 3 scientists (e.g., Lake Guardian scientists, scientists from shoreside partners) you have contacted since your participation in the Lake Guardian Shipboard Science Workshop. Type each scientist's name below and describe the type of interaction or requests made of that scientist (e.g., request for resources to share with students, clarification on a concept, virtual or actual classroom visit.)
    a. Scientist 1 (name and describe interaction):
    b. Scientist 2 (name and describe interaction):
    c. Scientist 3 (name and describe interaction):
9. Please identify up to 3 Center for Great Lakes Literacy staff you have contacted since your participation in the Lake Guardian Shipboard Science Workshop. Type each staff member's name below and describe the type of interaction or requests made of that person (e.g., request for resources to share with students, clarification on a concept, virtual or actual classroom visit).
    a. CGLL Staff 1 (name and describe interaction):
    b. CGLL Staff 2 (name and describe interaction):
    c. CGLL Staff 3 (name and describe interaction):
10. Please describe any communication about workshop content that you have had with scientists or educators who were NOT part of the Lake Guardian Shipboard Science Workshop. *(Please type in box below.)*
11. Please share any other comments you have about personal or professional impacts or experiences stemming from your participation in the Lake Guardian Shipboard Science Workshop. *(Please type in box below.)*