Assessment of

Environmental Literacy Project

Final Report – July 17, 2019

Mass Audubon
Protecting the nature *of Massachusetts*

RHODE ISLAND RiEEA
Environmental Education Association

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Assessment of Environmental Literacy Project

Report Summary

The following report describes the process and outcomes of a consulting project focused on the identification of a tool for supporting the assessment of environmental literacy to be piloted with K-12 students in Rhode Island. The project was managed by the Rhode Island Environmental Education Association. Mass Audubon, in collaboration with EF Games, LLC, provided research, facilitation, and consulting services that led to a clear recommendation for an *Assessment of Environmental Literacy* (AEL) tool.

The RIEEA AEL Project Team (RIEEA, Mass Audubon, and EF Games) met in person, via video conference and phone conference over the course of six months to complete a predetermined scope of work. The team developed a comprehensive environmental literacy literature review based on an initial literature review conducted by RIEEA. The literature review contained in this report ensured that any gaps in research were addressed and were used to inform the development process. This literature review generated a list of nearly seventy-five topics relevant to environmental literacy learning outcomes.

During a full-day meeting with RIEEA, the team reviewed this comprehensive list and prioritized twelve environmental literacy components and seventeen activities that would serve as indicators of proficiency in environmental literacy. This process was followed by a tool specifications exercise which informed the development of a complete tool requirements document that included both literacy components and technical specifications. Finally, a subset of critical environmental literacy and technical components was identified as the minimum requirements for a successful AEL tool.

A comprehensive list of potential online tools that could assess environmental literacy was developed and a subset of these tools was evaluated against these predetermined requirements. We considered both the existing state of each of the tools, and its potential to be adapted to serve as an AEL. No tool met all of the environmental literacy and technical components; however, Local Environmental Modeling (LEM), a tool that lets students create a land use plan that is responsive to environmental, social, and economic issues, met all of the *critical* technical and environmental literacy components described in this report.

While LEM was determined to be the final recommendation, modifications must be made to the current state of LEM in order to best meet the components and underlying activities that demonstrate proficiency in environmental literacy. The report describes the specifications for these modifications.

We also note that while LEM is the best tool for identifying growth in student learning around environmental literacy components, we cannot make claims about student environmental literacy at scale without validation studies.

With generous support from both the Pisces Foundation and the Rhode Island Foundation this past year, RIEEA has been successfully implementing Phase Two of the RI-AEL by conducting three major activities:

1. Sharing the Environmental Education Inventory of Current Practices survey tool and resulting data through local and national platforms;
2. Facilitating a series of Community Forums designed to feature content that appeals to the six sectors we identified in Phase One, to identify how the RI-AEL can support their work, and to inform the development of the RI-AEL; and
3. Evaluating existing online environmental literacy assessment tools, including the Local Environmental Modeling tool (LEM) developed by EF Games, LLC, to determine which would be the most appropriate to use as the basis for an RI-AEL tool, and what modifications, if any, would be required to the existing platform to make that possible.

Phase Three of the RI-AEL will build on the progress and momentum of the second phase and will help RIEEA continue the partnership with Mass Audubon and the University of Wisconsin-Madison's EF Games, LLC. RIEEA will:

1. Utilize the feedback solicited during our Community Forums;
2. Incorporate recommendations from the RI-AEL Advisory Council and RIEEA's Diversity Committee; and
3. Pilot the RI-AEL tool.

Review of Environmental Literacy: Key components, characteristics, and areas to assess

The following section is a report on the results of the Environmental Literacy Literature Review that was developed in winter 2019. The purpose of this report is to provide an overview of the key components, characteristics, and areas to assess on Environmental Literacy. This section represents one component of Phase Two of the RIEEA Assessment of Environmental Literacy project. It provides an overview of what environmental literacy is and why it is important, but the true focus of this segment is to provide an understanding of what key components and characteristics comprise environmental literacy and identify potential areas to assess, via a meta-analysis of reviews on environmental literacy.

Definition of Environmental Literacy

As addressed in the Rhode Island Environmental Literacy Plan (2011), the Rhode Island Environmental Education Association grounds its definition of environmental literacy in two seminal works: the Partnership for 21st Century Skills (2011) and the Campaign for Environmental Literacy (2011).

The Partnership for 21st Century Skills (2011) defines an environmentally literate student as one who can:

- Demonstrate knowledge and understanding of the environment and the circumstances and conditions affecting it, particularly as relates to air, climate, land, food, energy, water and ecosystems
- Demonstrate knowledge and understanding of society's impact on the natural world (e.g., population growth, population development, resource consumption rate, etc.)
- Investigate and analyze environmental issues, and make accurate conclusions about effective solutions
- Take individual and collective action towards addressing environmental challenges (e.g., participating in global actions, designing solutions that inspire action on environmental issues) (Partnership for 21st Century Skills, 2011)

The Campaign for Environmental Literacy (2011) defines environmental literacy as:
the capacity of an individual to act successfully in daily life on a broad understanding of how people and societies relate to each other and to natural systems, and how they might do so sustainably. This requires sufficient awareness, knowledge, skills, and attitudes in order to incorporate appropriate environmental considerations into daily decisions about consumption, lifestyle, career, and civics, and to engage in individual and collective action. The Campaign for Environmental Literacy (2011) further describes five essential components of environmental literacy. These components are: awareness, knowledge, attitudes, skills, and action.

Importance of Environmental Literacy

With a global population of more than 7 billion and growing (US Census, 2019), our planet is closely approaching its carrying capacity. Our planet is warming, our climate is changing, and the natural resources that we rely on for food, water, and energy are limited. With this uncertain future comes an ever more pressing need to educate and engage our young people to innovate towards ecologically sustainable solutions for the benefit of the natural world upon which humankind relies. We must teach for and foster the development of environmental literacy.

Teaching for environmental literacy is a core goal of environmental education (NAAEE, 2019). To reach this goal it is imperative that the teaching of environmental literacy becomes a core area of focus in our K-12 schools. In the Environmental Education: Inventory of Current Practices survey that was administered to Rhode Island teachers and administrators in Spring 2018 by RIEEA, the majority of respondents agreed that environmental education (EE) should be considered a K-12 priority, it is important for teachers to integrate environmental issues into their teaching, and that districts should develop and implement EE curriculum. Teacher and administrator respondents tended to agree that EE provides meaningful learning experiences, enhances learning and supports other subjects, and integrates real world experiences into student learning. While teachers were more likely than administrators to agree that environmental literacy is an important component of scientific literacy, administrators indicated greater awareness of the positive academic and social impacts of EE on students and teachers. Both groups also disagreed that EE is successfully taught only by science teachers or appropriate mainly for science/social studies, is an "add on," and takes time away from mandatory subjects. The results of this inventory clearly support not only the need for building environmental literacy, but also the unanimous support for making it a part of K-12 learning.

Methods

Because the repository for information on environmental literacy is quite large and the goals for this work were unique to RIEEA, this report focused its data sources in three key areas--RIEEA artifacts (graphics, documents, reports, and meeting minutes), peer reviewed literature reviews, and original seminal works on environmental literacy.

In total, 17 data sources were identified for review on this project. Initially all 17 data sources were vetted for relevance and accuracy to the goal of identifying key components of environmental literacy. Those data sources that were not deemed to be grounded in research or relevant to the project goal were eliminated. Those that were eliminated primarily consisted of RIEEA meeting minutes and the RIEEA AEL Environmental Education Inventory survey results, as these sources, although very useful in understanding the on-going work of RIEEA and the landscape of environmental education in K-12 schools in Rhode Island, did not have an explicit focus on identifying central components of environmental literacy. Additional data sources that were eliminated included works that focused only peripherally on areas related to environmental literacy, such as sustainability literacy and ecological literacy. In total, ten sources were deemed appropriate to review for this project.

Because the state of Rhode Island has adopted the Next Generation Science Standards (NGSS), and it is a goal of RIEEA to assess environmental literacy in school, this review also included a brief review of the NGSS as it relates to environmental education and building environmental literacy. The addition of an NGSS review brought the total number of documents to review to 11. The sections that follow provide a summary of all documents that were a part of the final review process. The goal was to identify the key elements of environmental literacy that would be feasible to explore through the lens of developing an environmental literacy assessment tool. For each source, a summary of the work is provided, followed by a detailed list of components and sub-components of environmental literacy as described in each source.

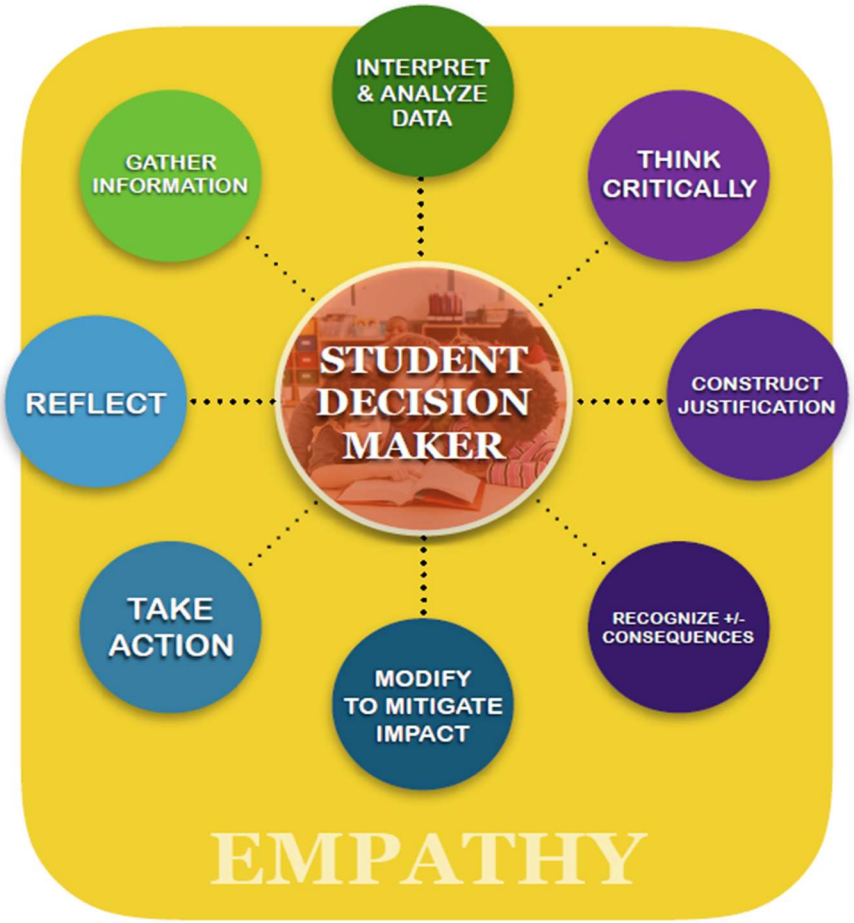
Source Reviews

1. RIEEA 2018 Environmental Literacy Concept Map

Abstract/Summary:
A graphic designed by RIEEA as a vision for EL was discussed and outlined by the RIEEA board and AEL Advisory Council. The concepts behind the graphic were pulled from Common Core and NGSS principles. This map puts "student decision maker" in the center.

Key Components of EL:

- Reflection
- Taking Action
- Modify to mitigate
- Recognize Consequences
- Construct Justification
- Think Critically
- Interpret and Analyze Data
- Gather Information
- Empathy



2. Hollweg, K. S., Taylor, J. R., Bybee, R. W., Marcinkowski, T. J., McBeth, W. C., & Zoido, P. (2011). Developing a framework for assessing environmental literacy. Washington, DC: North American Association for Environmental Education. Available at http://www.naaee.net.

Abstract/summary:
This document presents a comprehensive, research-based description of environmental literacy and applies that work to the creation of a framework for an assessment of environmental literacy. The developers, who worked under the aegis of the North American Association for Environmental Education (NAAEE), sought to create materials that are broadly representative of, and build on, the environmental education literature, as well as insights derived from a broad range of disciplines. Their work was informed by: previous environmental education frameworks (e.g., Hungerford & Volk, 1990; Roth, 1992; Simmons, 1995; Wilke, 1995); recent national assessments of environmental literacy in the United States (e.g. Phases One and Two of the National Environmental Literacy Assessment Project (NELA); McBeth et al., 2008, 2011) and in other nations (e.g., South Korea: 2002-2003; Israel: 2004-2006: and Turkey: 2007-2009); and the Organization for Economic Co-operation and Development's (OECD's) international

assessments (e.g., the OECD report Green at Fifteen? How 15-Year-Olds Perform in Environmental Science and Geoscience in PISA 2006 [OECD, 2009]).

Proposed framework for environmental literacy (see Developing a Framework for Assessing Environmental Literacy, 2011 p. 5-18):

- **Context** (local, regional, or global situations that involve the environment)
- **Competencies** (ID env issues, analyze env issues, evaluate potential solutions to env issues, propose and justify actions to address env issues)
- **Environmental Knowledge** (about physical ecosystem, env issues, sociopolitical, strategies for addressing env issues)
- **Dispositions toward the environment** (How a person responds to env issues--interest, sensitivity, locus of control, responsibility, intentions to act)

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3. Marcinkowski, T. (2010). Major features of environmental literacy. Unpublished document, Department of Science and Mathematics Education, Florida Institute of Technology, Melbourne, Florida.

Abstract/Summary:
This document presents a table outlining key domains of EL as well as related focal points around “Nature”, “Environmental Problems and Issues”, and “Solutions and Sustainability”.

Key Components of EL:

- **Knowledge** (knowledge of natural history, knowledge of problems, knowledge of solutions)
- **Skills** (field and lab skills in nature study, skills in identifying and analyzing problems, skills in planning and implementing solutions)
- **Affective Domain** (attitudes and values associated with nature, environmental concerns about environmental problems, willingness to serve or act on concerns)
- **Participation Behavior** (participate in nature-based outdoor activities, participate in regional/national issues, participate in responsible behavior)

Domain	Nature	Env Problems and Issues	Solutions and Sustainability
Knowledge	• Knowledge of natural history and ecology	• Knowledge of problems and issues	• Knowledge of past and potential solutions to problems • Knowledge of issue resolution and social change strategies • Knowledge of service/action strategies available
Skills	• field /lab skills used in studies of nature	• field/lab skills used in monitoring problems, and analyzing and interpreted data on problems • Skills used in identifying, analyzing, investigating, and evaluating issues.	• Skills involved in identifying, analyzing, investigating, and evaluating past and alternative proposed solutions • Skills involved in planning, implementation, and evaluating service/action projects.
Affective dispositions	• Environmental sensitivity • Attitudes and values associated with nature.	• Environmental concerns or attitudes, and values associated with problems and issues.	• Personal responsibility • efficacy/locus of control • Willingness to serve/act
Participation (behavior)		• Participation in various problems and issues in the community, county, state, national.	• Participation in responsible environmental behavior, individually, and collectively at various levels.

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4. McBride, B.B., Brewer, C. A., Berkowitz, A.R., Borrie, W. T., (2013). Environmental Literacy, ecological literacy, ecoliteracy: What do we mean and how did we get here?, Ecosphere. 4 (5) pp. 1-20.

Abstract/Summary

A review of a diversity of perspectives related to the often nuanced differences and similarities of these terms--Environmental literacy, ecological literacy, ecoliteracy. A classification of numerous proposed frameworks for environmental literacy, ecological literacy, ecoliteracy, is presented, and used to compare and contrast frameworks across multiple dimensions of affect, knowledge, skills, and behavior.

Components of EL (based on their review of: Strap & Cox (1974), UNESCO (1977), Hungerford et al. (1980), Ballard and Pandya, (1990), Curriculum task group, ASTM (1990), Marcinkowski, (1991), Wisconsin Center for EE (1992/1997), Roth (1992), PLT (1993/2006), Hungerford, et al. EL Consortium (200/2004), NAAEE (2002/2004), NSTA (2003), Coyle (2005), McBeth et al. (2006), NAAEE (2011).

- **Affective** (environmental sensitivity and appreciation)
- **Knowledge** (ecological, socio-political, environmental issues)
- **Skills** (cognitive; identify and define env. problems)
- **Environmentally responsible Behavior** (active participation in problem solving)
- **Additional determinants of Env. Responsible Behavior** (Locus of control and assumption of personal responsibility--perception to bring about change)

Components of Ecological literacy (based on their review of: Risser (1986), Cherret (1989), Kelmow (1991), Odum (1992). Berkowitz (1997), Berkowitz et al. (2005), Jordan et al. (2009), Powers (2010).

- **Knowledge** (ecological, socio-political, environmental issues)
- **Cognitive** (scientific inquiry)
- **Additional determinants of environmentally responsible behavior**

Components of Ecoliteracy (based on their review of: Orr (1992), Capra (1997, 2002, 2013), Cutter-Macenzie and Smith (2003), Woolorton (2006).

- **Affective**
- **Knowledge** (Ecological, socio-political, environmental issues)
- **Cognitive skills**
- **Env. responsible behavior**

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5. Assessing Environmental Literacy, Roberta Hunter, Rutgers Graduate School of Education. PowerPoint presentation from NAAEE Research Symposium 2015

Abstract/Summary

This document provides a review of environmental literacy and environmental literacy assessment. Specifically, it examines the work or Roth (1992), Stables (1998,2001), Hungerford, Peyton, & Wilke (1981), UNESCO (1990), SImmons (1995), Jordan, SInger, Vaughan, Berkowitz (2009), Hollweg et al (2011), McBeth, Hungerford, Marcinkowski, Volk, & Cifranik (2011). Negev, Sagy, Garb, Salzberg, & Tal (2008).

Key components of EL:

- **Knowledge**
- **Beliefs**
- **Affect**
- **Skills**
- **Behavior**

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6. RIEEA workshop November 19, 2018 Notes

Abstract/Summary
K-12 Guidelines and Assessment of Environmental Literacy. A workshop summary that compared three models of key features of EL--RIEEA 2018 Empathy model, Tom Marcinkowski's Major Features of EL, and NAAEE K-12 Guidelines for Excellence. A team of educators analyzed each document to pull out overlapping key areas of environmental literacy. Following comparison, this group determined that the most important elements of EL assessment could be found in the K-12 Guidelines for Excellence.

Key areas to assess EL:

- **Knowledge** (content on collecting information, understanding of human systems and environment in society--see guidelines 1C, 2.2 and 2.3)
- **Skills** (Cognitive skills for analyzing and investigating environmental issues, decision making and action skills--see guidelines 3.1 and 3.2)
- **Attitude/Action and willingness to act** (Recognizing efficacy and developing agency, accepting personal responsibility--see guidelines 4b and 4c)

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7. Ardoin, N. M., Bowers, A. W., Roth, N. W., & Holthuis, N. (2017). Environmental education and K-12 student outcomes: A review and analysis of research. The Journal of Environmental Education, 1–17. https://doi.org/10.1080/00958964.2017.1366155

Abstract/Summary
Ardoin and colleagues conducted a systematic review of peer-reviewed articles about environmental education learning outcomes for K-12 students. They found 119 articles that matched the search criteria, resulting in 121 unique learning outcomes across the studies. The authors also identified research designs, methods of data collection, and other structural variables.

They further categorized outcomes into 6 categories:

- **Knowledge** (including awareness, perceptions, content knowledge, skills knowledge, socio-political knowledge, and issue-specific understandings);
- **Dispositions** (such as, interest, affect, attitude, and behavioral intentions);
- **Competencies** (skills, including cognitive and social);
- **Behavior** (actions);

- **Personal characteristics** (self-esteem and character development, among others); and
- **Multi-domain outcomes** (those spanning more than one domain, such as academic achievement, which involves at least knowledge and competencies--see page 8).

Summary of Review of 119 articles

Outcome Domain	**# of articles measuring this domain**	**Percentage of articles measuring this domain**
Knowledge	81	68%
Dispositions	73	61%
Competencies	31	26%
Behavior	24	20%
Multi-domain outcomes	7	6%
Personal Characteristics	3	3%

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8. McBeth, B. Hungerford, H., Marcinkowski, T., Giannoulis, C., Volk, T., and Cifranick, K. (2014). National Environmental Literacy Assessment, phase two: Measuring the effectiveness of North American environmental education programs with respect to the parameters of environmental literacy. Retreived from NAAEE https://cdn.naaee.org/sites/default/files/eepro/resource/files/finalresearchreport.pdf

Abstract/Summary
The purpose of this study was: 1) To identify environmental literacy levels of middle school students involved in on-going school-based environmental programs; 2) To compare environmental literacy levels of middle school students involved in on-going school-based environmental education programs to those of the NELA Phase One Baseline sample; 3) To identify middle schools where students exhibit high levels of environmental literacy for further study.

This study addressed the questions: 1) What is the level of environmental literacy of sixth, seventh and eighth-grade students in the U.S. who are participating in established school-based environmental programming, on each of the following variables: a. ecological knowledge; knowledge; b. verbal commitment [intention to act]; c. environmental sensitivity; d. general environmental feelings [environmental attitudes]; e. environmental issue and action skills; f. actual commitment [environmentally responsible behavior]? 2) How does the level of

environmental literacy of students in these selected schools compare with the baseline level of environmental literacy among sixth and eighth-grade students? Students scored the lowest in cognitive skills--issue ID, issue analysis, action planning.

Areas assessed:

- **Ecological knowledge**
- **Verbal commitment** (intention to act)
- **Environmental sensitivity**
- **General environmental feelings**
- **Environmental issue and action skills**
- **Actual commitment** (environmentally responsible behavior)

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9. Minner, D. & Klein, J. (2016). A case for advancing an environmental literacy plan in Massachusetts: Phase I—a summary of the Commonwealth's environment and education landscape. Report by Massachusetts Environmental Education Society. Retrieved from www.mees.org.

Abstract/Summary

This document is not an environmental literacy implementation plan, rather it is designed to serve as a foundation for advancing environmental literacy in one state, Massachusetts, and is used to guide environmental literacy in the Commonwealth of Massachusetts. This report provides an overview of EL--its definition, components, history, and intersections across sectors and initiatives in MA. Parallels can be made to the work that is done in RI.

Key components of an Environmentally Literate person:

- Understands ecosystems and how they function
- Thinks critically about how human actions affect ecological functioning and subsequent environmental issues/problems that arise
- Appreciates natural phenomena and biodiversity through observation and direct experiences in natural settings
- Participates in action planning for themselves and their community to address environmental issues.

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10. EPA. (2019). What is environmental education? Retrieved January 28, 2019, from https://www.epa.gov/education/what-environmental-education.

Abstract/Summary

The EPA gives an overview of what environmental education is as well as what the key components of EE are. Without explicitly calling out environmental literacy it does offer five key components of EE that align well with environmental literacy.

The components of environmental education are:

- **Awareness and sensitivity** to the environment and environmental challenges
- **Knowledge and understanding** of the environment and environmental challenges
- **Attitudes** of concern for the environment and motivation to improve or maintain environmental quality
- **Skills** to identify and help resolve environmental challenges
- **Participation** in activities that lead to the resolution of environmental challenges

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11. NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academy Press.

Abstract/Summary

With the goal of improving science education, the *Next Generation Science Standards* (NGSS) were developed through a collaboration between science experts, educators, and researchers in order to create a vision and, consequently, a new set of education standards. These standards proposed and organized important and overarching themes in science into what the standards call 3-dimensional learning including crosscutting concepts, disciplinary core ideas, and science and engineering practices. Instead of learning content and then applying it, the NGSS proposed an integrated and holistic view of science education. Additionally, because we are creating assessments for students in grades 5-12 we propose that these standards are included to meet state targets for the assessment of targeted NGSS content and skills.

Science and Engineering Practices

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Cross Cutting Concepts (CCC)

- Patterns
- Cause and Effect
- Scale, proportion, and quantity
- Systems and system models
- Energy and Matter
- Structure and function
- Stability and change

Disciplinary Core Ideas (specific to environmental work that span across the disciplines)

- Biodiversity and Humans

- Defining engineering problems
- Developing possible solutions
- Ecosystem Dynamics, Functioning, and Resilience
- Global Climate Change
- Human Impacts on Earth Systems
- Natural hazards
- Natural resources
- Weather and climate

Approach

One approach to assessment validity is evidence-centered design (ECD; Mislevy, 1996), which argues that assessments should use collective evidence to warrant claims about student learning. This framework proposes that researchers approach assessment by considering what knowledge, skills, or abilities they are measuring, what evidence is collected to measure those components, and with what activities they can measure such constructs. ECD prioritizes being deliberate and thoughtful about how researchers obtain evidence from assessments and what that evidence reveals.

Learning Outcomes

The literature review generated a list of nearly 75 topics relevant to EL shown in the **Learning Outcomes by Source** chart (Appendix A). Through a process of combination, consolidation, and dismissal, the list was refined to include twelve key Components of Environmental Literacy, and seventeen Activities that indicate some level of proficiency in those Components.

SKIVE

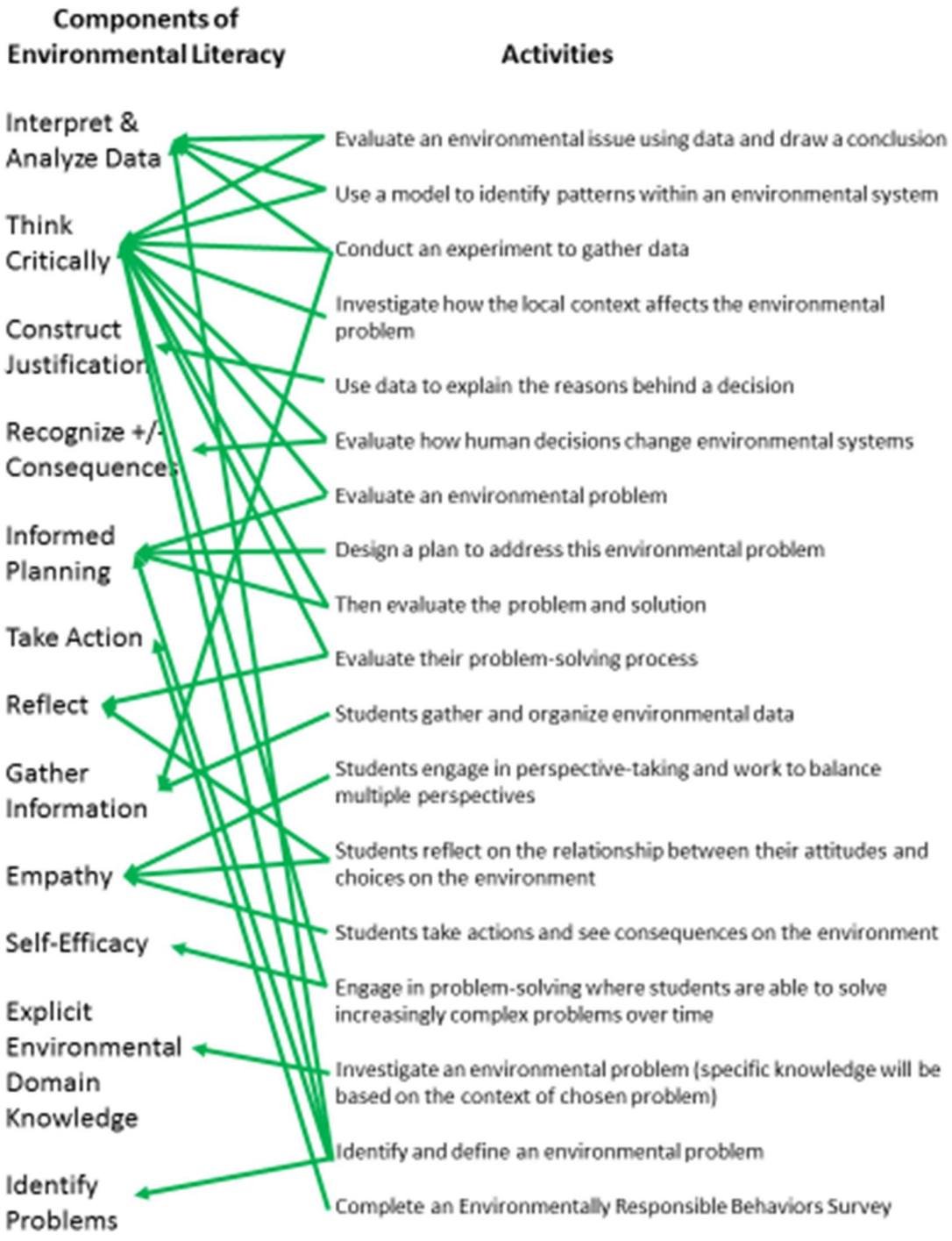
We used Shaffer's (2012) epistemic frame theory as a guide for how we might consider what collective evidence demonstrates environmental literacy. Shaffer's theory suggests that people engaging in a community of practice develop a pattern of associations among knowledge, skills, and habits of mind that characterizes that community of practice, or groups of people who share similar ways of framing, investigating, and solving complex problems. This theory considers how the following ideas constitute a way of thinking about the world:

1. **Skills**: the things that people do
2. **Knowledge**: the understandings that people in that community share
3. **Identity**: the ways community members see themselves
4. **Values**: the beliefs that members of the community hold
5. **Epistemology**: the ways members justify actions within the community

Taken together, these elements, often abbreviated as SKIVE, are connected and produce an epistemic frame for seeing the world and solving problems. During our discussions, we used SKIVE as a scaffold to develop a set of meaningful and diverse set of Activities for the assessment of environmental literacy.

The **Components of EL by SKIVE** chart (Appendix B) breaks down the specific Skills, Knowledge, Identity, Values, and Epistemology attached to each Component, and notes which Activities can be evaluated to assess students' understanding of the Components.

The chart below is a graphic representation of the relationship between the *Components of Environmental Literacy* and associated *Activities* that demonstrate proficiency in environmental literacy.


Components of Environmental Literacy
Activities
Interpret & Analyze Data
Think Critically
Construct Justification
Recognize +/- Consequences
Informed Planning
Take Action
Reflect
Gather Information
Empathy
Self-Efficacy
Explicit Environmental Domain Knowledge
Identify Problems
Evaluate an environmental issue using data and draw a conclusion
Use a model to identify patterns within an environmental system
Conduct an experiment to gather data
Investigate how the local context affects the environmental problem
Use data to explain the reasons behind a decision
Evaluate how human decisions change environmental systems
Evaluate an environmental problem
Design a plan to address this environmental problem
Then evaluate the problem and solution
Evaluate their problem-solving process
Students gather and organize environmental data
Students engage in perspective-taking and work to balance multiple perspectives
Students reflect on the relationship between their attitudes and choices on the environment
Students take actions and see consequences on the environment
Engage in problem-solving where students are able to solve increasingly complex problems over time
Investigate an environmental problem (specific knowledge will be based on the context of chosen problem)
Identify and define an environmental problem
Complete an Environmentally Responsible Behaviors Survey

Prioritizing Components of Environmental Literacy

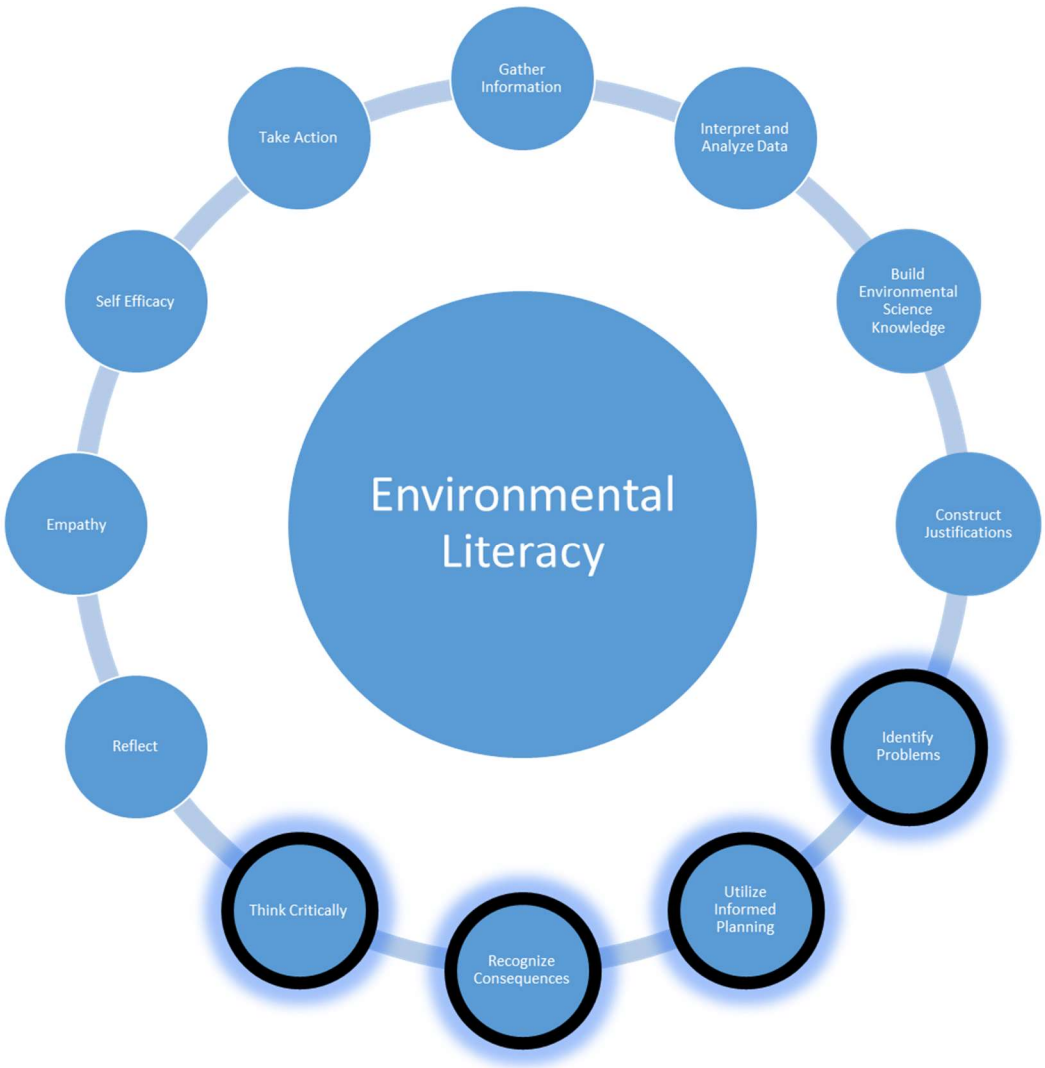
As discussed above, the AEL Project Team identified twelve components for assessing environmental literacy: self-efficacy, take action, reflection, gather information, interpret and analyze data, build environmental science knowledge, construct justifications, identify problems, utilize informed planning, recognize consequences, think critically, and empathy. Of these components, four components were considered as core to environmental literacy and were valued higher than other components:

1. think critically,
2. identify problems,
3. recognize positive and negative consequences, and
4. utilize informed planning.

One component, and also the desired outcome, of many environmental education endeavors is taking action. Although this is identified as an important component of environmental literacy, the nature of digital tools and assessments is that they are online or on a computer and not necessarily affecting the real world. Many studies try to address the idea of taking action by assessing the closest thing to actually acting: intending to take action. Typically, studies ask participants to fill out a questionnaire (e.g. Environmentally Responsible Behaviors survey) which allows participants to indicate what activities they have done or intend to do. While this can provide information about behavior and inclination it is not actually an action. Further, none of the tools explicitly allow students to take action and the only way action may be incorporated is through adding a survey. For this reason, taking action or intending to take action were determined to be a low priority when assessing tools for this report.

Revised Concept Map

An unintended outcome of the environmental literacy component refinement and prioritization process was to develop a suggested revision of RIEEA's Environmental Literacy Concept Map. This proposed new concept map illustrates the 12 components of Environmental Literacy while highlighting the four core components identified in the prioritization process.


Environmental Literacy
Gather Information
Interpret and Analyze Data
Build Environmental Science Knowledge
Construct Justifications
Identify Problems
Utilize Informed Planning
Recognize Consequences
Think Critically
Reflect
Empathy
Self Efficacy
Take Action

Tool Assessment

Having defined the relevant components of EL through the literature review and determined the core tool requirements in conjunction with RIEEA, the next step was to discover which tools might be worthy of close review. A long list of tools identified through various sources was narrowed down to a short list of six tools meeting all the usability specifications.

Identifying tools to review

We cast a wide net to identify the most relevant and appropriate tools for this project, including online game hubs, app based games, and online games. Upon searching for tools, we looked for games, simulations, tools, and assessments that might plausibly address components of environmental literacy and the chosen technical requirements. Some of our tools were found during the literature review earlier in this process. Other tools were found using Google website searches and Google Scholar searches. The list of portals and games that were explored included:

Hubs for multiple online games

- Annenberg Learner
  Ex. Carbon Lab, Shrinking a Landfill, Earth's Plates
  http://www.learner.org/interactives/?per_page=20&disciplines%5B0%5D=SCI&page=1
- Kid's Corner Animal Games- Sheppard Softwares
  Ex. Animal Diet 1, Endangered Animals, Producers Consumers
  http://www.sheppardsoftware.com/content/animals/kidscorner/kidscorner3.htm
- Space Place- NASA
  Ex. Greenhouse Gas Attack!, Ozone Trap-n-Zap!
  https://spaceplace.nasa.gov
- Switch Zoo Animal Games
  Ex. Build a Biome, Sound Match, Where Do I Live?
  https://switchzoo.com/default.htm
- WebRangers- National Park Service
  Ex. Dino Diets, Turtle Hurdles, The Puma Challenge
  https://www.nps.gov/webrangers/entry_gate.cfm

Online Games and Tools

- Block'hood (Steam) - Plethora Project
  https://www.plethora-project.com/blockhood/
- Catchment Detox
  http://www.abc.net.au/science/catchmentdetox/files/play-game.htm
- City Rain - Ovolo Games
  http://www.ovologames.com/cityrain/
- ECO - Strange Loop Game
  https://www.strangeloopgames.com/eco/

- ElectroCity - Genesis
  http://www.electrocity.co.nz/Game/game.aspx
- Enercities
  https://www.enercities.eu
- Evolution Lab - NOVA Labs
  https://www.pbs.org/wgbh/nova/labs/lab/evolution/research#/chooser
- Forgotten Island - Citizen Sort
  https://citizensort.org/web.php/forgottenisland
  https://www.sciencedirect.com/science/article/pii/S074756321500432X?via%3Dihub
- Garbage Dreams
  http://www.pbs.org/independentlens/garbage-dreams/game.html
- Green City
  https://www.bigfishgames.com/games/7548/green-city/
- Habitat
  http://www.habitatthegame.com
- Ice Flows - University of Exeter
  http://www.iceflowsgame.com/iceflowsgame.html
- Intrigue 2016 (might not be accessible anymore)
  http://serious.gameclassification.com/EN/games/16409-Intrigue-2016/index.html
- One Ocean Online - Complex Games
  http://complexgames.com/game/one-ocean-online/
- Fierce Planet Game
  https://www.researchgate.net/publication/262292574_Simulating_a_'fierce_planet'_a_web-based_agent_platform_and_sustainability_game
- World Without Oil
  http://writerguy.com/wwo/metahome.htm
- ONPAR
  http://iiassessment.wceruw.org/projects/ONPAR-science-tasks.html
- Web-based Inquiry Science Education (WISE)
  https://wise.berkely.edu
- Quest Atlantis
  https://sashabarab.org/activity/arx-the-mystery-of-taiga-river/
- Local Environmental Modeling
  https://lem.epistemic-games.org

Mobile Apps

- Amazing World OCEAN 3D (iOS) - Dimitar Itskov
  https://itunes.apple.com/us/app/amazing-world-ocean-3d/id957293784?mt=8
- Climate Defense (Android)
  http://gamethenews.net/index.php/climate-defense/
- Deep Blue Dump (iOS and Google Play) - Stories Studio W.L.L.
  https://www.thestoriesstudio.com/deep-blue-dump
- NAMOO Wonders of Plant Life (iOS) - CRAYON BOX Inc.
  http://namooapp.com/?ckattempt=1

- Grow Forest (iOS and Google Play) - Gro Play
  https://www.groplay.com/apps/grow-forest/
- Grow Garden (iOS and Google Play) - Gro Play
  https://www.groplay.com/apps/grow-garden/
- iBiome Ocean (iOS) - Springbay Studios Ltd.
  https://itunes.apple.com/us/app/ibiome-ocean/id1207917622
- iBiome Wetlands (iOS)- Springbay Studios Ltd.
  https://itunes.apple.com/us/app/ibiome-wetland/id900933868
- Little Mouse's Encyclopedia (iOS) - Circus Atos
  https://littlemousesencyclopedia.circusatos.com
- Phyto Heroes (iOS) - University of Maine
  http://phytoheroes.com
- Plants by Tinybop (iOS) - Tinybop Inc.
  https://itunes.apple.com/us/app/plants-by-tinybop/id872615882?mt=8

As a byproduct of this review, we gathered insights into helpful tool features:

- The pros of using a live facilitator when implementing the tool (Stave, Beck, & Galvan, 2015).
- Potential for strong ceiling effect regarding environmental action – it could bias assessment results if there is a specific subset of players who are already maximally committed to environmental action (Waddington & Fennewald, 2018).
- Simulation games should induce participants to feel ownership of the problem (Loureiro et. al., 2018).
- To make the game experience more enjoyable there should be a story (benefit of continual play) that provides a motivating purpose (Prestopnik & Tang, 2015).
- Whether the tool delegates specific roles to participants. This would make individual assessment more difficult, but would be a better representation of real-world environmental planning and management (Le Page et. al., 2016).
- A debriefing with or without an in-person facilitator, followed by a short reflective multi-choice quiz, may be beneficial after participants play the game – however, this was suggested to be important to learning tools specifically, not assessment tools. This could be beneficial before participants play our game for better implementation (Stave, Beck, & Galvan, 2015).

Tool Requirements: Usability Specifications

Before analyzing tools, the AEL Project Team identified an additional set of tool requirements. In addition to the tool being able to provide evidence of environmental literacy components, it also needed to meet playability, customization, and usability requirements. These tool requirements, or usability specifications consisted of: amount of time, technology platform required, access to student data, replayable, customizable, adaptive complexity, scalable, minimal teacher training, and grade level appropriateness. These requirements provided a way to frame our analysis of existing tools by identifying important features or components.

Amount of time

The amount of time refers to the length of time to complete the activity. Because the ideal implementation would be in a classroom, the ideal amount of time would be 45 minutes or less to fit within a typical class period. If the assessment needed to be in two parts or could be paused and revisited, then the amount of time could be 60 or 90 minutes and broken into two class periods.

Technology platforms and requirements

Students will engage in the activity using a computer, tablet, or phone. Most schools use Chromebooks, laptops, and/or tablets, and therefore the tool should be usable on these platforms. The ability to access the tool via mobile phones would be helpful although not a requirement. The program should be useable by many students accessing the program at the same time without crashing. The assessment may be online or downloaded, though online platforms are preferred. While online platforms may be preferred, the group also discussed how many schools may have internet access, yet this access may not always be available or consistent.

Access to student data

In order to use a tool as an assessment, the tool should provide access to student data in order to see what and how the students perform. Ideally, the research team would have access to both process and outcome data. This data may also be shared with classroom teachers and other personnel. A teacher dashboard would be helpful but is not a necessary requirement.

Replayable

Replayability is important for several reasons. First, students could take the assessment multiple times and provide data on student progress. Second, replayability often means that there is more than a single outcome or answer. Another factor that replayability addresses is contamination of the assessment. If there is a single outcome, students in earlier classes may talk with their peers. This cross-talk may skew the student results. Replayability may occur using problem isomorphs, variable complexity of problem space, and/or multi-outcome problems. Problem isomorphs are different questions that use the same problem-solving strategy and have the same underlying structure thus allowing ways to assess the same skill using a different problem.

Customizable
Customization refers to changing or adapting the tool for student, local, district, or other needs. Customization would allow teachers or the research team to adapt the tool for use within a given classroom or context. Customization would further allow the research team the ability to modify an assessment for new or localized contexts and scenarios. The ideal tool would be able to be deployed in a variety of contexts and assess all of the necessary components of environmental literacy. If the tool is unable to meet some of the literacy components, then the ideal tool could be changed to meet those requirements.

Adaptive complexity
Assessments with adaptive complexity use student choices and correctness to choose different problem paths. This feature increases or decreases the challenge to match student skill level.

Scalable
Scalability would allow the assessment to be used for increasing numbers of students. The ideal tool would be created for Rhode Island but would be useable in multiple other states as well. In order to scale for increasing numbers of students and locations, this concept of scalability addresses the capacity of the tool, administration of the tool, and assessment of student data. The ideal tool would be usable by many students across states while reducing the burden for teacher or researcher implementation or intervention.

Minimal teacher training
Teachers play an important role in administering the assessment. The ideal tool would require minimal to no required teacher professional development.

Grade level
In the first phase of this assessment, the tool would be geared for 8th-grade students with the possibility to expand both up and down, into the rest of middle and high school. Future development may consider creating versions for elementary school populations.

Prioritizing Tool Requirements

Of these nine tool requirements, three were identified as critical components: *data access*, *scalability*, and *teacher training*. First, the research team would need access to the data or some form of data in order to use the experience as an assessment. Secondly, the tool should be useable across Rhode Island and other states without a high implementation requirement. It should also remain valid in those states. Finally, and related to scalability, the tool should require minimal teacher training. For scaled-up use, the tool would need to be viable in many contexts and environments. Minimal training would allow easier use in classrooms and low to no preparation for teachers or researchers.

Comparative Tool Review

After trying to identify as many known tools as we could, we focused our search on science and environmental tools that were interactive, free, and publicly available. Additionally, if a tool did not seem like it could reasonably meet roughly half of the literacy and technical requirements it was removed from the review.

After preliminary searches, six tools were identified for comparison:

1. ElectroCity
2. Citizen Science
3. The Mystery of Taiga - Quest Atlantis
4. Web-based Inquiry Science Education
5. ONPAR
6. The Local Environmental Modeling System

For each of these six tools, we summarize the tool, provide a list of advantages and disadvantages, assess environmental literacy components, and assess tool requirements. We then provide a table summary to compare which requirements are met for each tool.

ElectroCity - Genesis

ElectroCity is an online computer game that lets players manage their own virtual towns and cities. It's great fun to play and also teaches players all about energy, sustainability, and environmental management in New Zealand. It's free and can be played on any computer that has Flash 8 or higher installed. It's easy to learn, but there is a lot of complexity for more advanced players. It's easy and flexible for teachers to set up and manage. You register once and students don't need to register at all. There's no correct way to play and many different approaches can lead to success. This is not a game of right and wrong, but of pros and cons. http://www.electrocity.co.nz/Game/game.aspx

While this tool was free and publicly available at the time we chose our top tools to review and when we conducted the initial part of our review, when we analyzed the tool for this comparison we found that it was no longer available.

Advantages:
This tool provides a simplistic simulation of land management. This tool would require little training to administer and little funding for implementation as long as the school has internet access and computers for every student. It has several levels of difficulty which would enable the game to be administered in different grades.

Disadvantages:
This tool fails, however, to encapsulate diverse geographical spaces. Users interact with one specific biome – most likely deciduous forest – and only in a green season. The model is very simple, and it may not be scaled to resemble actual places. The geographic markers are not specific; there is a body of water, a river, mountains, plains, and forest but there is only one identifiable version of each of these landmarks. For example, if the Hudson River were to be depicted in this game, it would not be pictured differently than any other river besides shape. The graphics are not detailed enough to distinguish multiple types of geographic characteristics. The primary disadvantage is that this tool is no longer supported or available.

Amount of time:
Approximately 30 minutes.

Technology platforms and requirements:
This tool requires internet access and computers. Each computer would require Flash 8 or higher installed. Only tablets that can download Flash can be used.

Access to student data:
Based on the website and documents there seem to be no available data other than win or loss states. Game developers may have access, but it is a free online game so it is unclear if this data is stored by the developers.

Replayability:
This is only somewhat replayable based on a single setting and easy solution paths.

Adaptability options:
There are no current options to adapt.

Adaptive complexity:
This game already has difficulty “modes”, but this does not mean that it changes gameplay based on student skill.

Scalability:
This game can be played by multiple users but may not scale for multiple locations.

Amount of teacher training necessary:
This is a very user-friendly game that provides instructions for independent play. No teacher training is required.

Grade level:
Middle school and high school

Citizen Science

Citizen Science is an adventure puzzle game where the player is taken back through time to help stop the pollution of their local lake. As the player travels back in time, they are challenged to not only learn about the overlapping and many causes of freshwater lake pollution but also the social factors and different constituents that play a role in the cause of certain pollutants. This game is a place-based adventure game where players learn about historical, social, economic, and environmental problems about a local lake. Set at Lake Mendota, in Madison, WI, students travel through time, interact with a lake monster, and in a strange twist the hippie college version of their own father. Players interact with local characters (and a fiery muskrat) to collect scientific evidence such as Secchi disk reading to test the turbidity of water in different locations of the lake. Players pass through recognizable local landmarks including the Memorial Union Terrace and the University of Wisconsin Limnology building. Students walk through lakefront places to investigate the causes of lake eutrophication (e.g. litter, phosphorus runoff from homes and agriculture, invasive species) and competing interest in lake usage (e.g. regulating fishing, wetland restoration, building land buffers). Students can test the causes of degradation in a time-lapse globe simulation of Mendota Lake before and after interventions such as construction regulations, exotic mussel introduction, and rain garden planting. Students then use information from conversations with locals and simulation data to construct scientific arguments about what is happening and what should be done. All the evidence gathered can be used to create "arguments" that are key in being used to change the future. In addition, players at times are asked to gather various data with different scientific tools to help aid in the story's progress. This allows players to attach a real-world context to the research that is done to understand freshwater science.
http://www.gamesforchange.org/game/citizen-science/

While this tool was free and publicly available at the time we chose our top tools to review and when we conducted the initial part of our review, when we analyzed the tool for this comparison we found that it was no longer available.

Advantages:
This tool provides students the opportunity to develop arguments and complete activities that address lake ecology. The bright colors and fantastical time traveling scenario make this game appealing to students and enjoyable during gameplay. The multiple interactions and activities could be screened to assess environmental literacy as the student works their way through the plot to save Lake Mendota. Multiple authors have written about this game and published theoretical and research articles in peer-reviewed journals.

Disadvantages:
The primary disadvantage of this game is that it may no longer be available. Similar to ElectroCity, Citizen Science was available at the time we chose it for review and conducted initial testing. However, we were unable to access a site for the tool analysis. Further, this tool lacks adaptability. The storyline aspect makes the context less malleable to local environments. Also, it is intended to be a learning tool for 5th-7th grade, not an assessment tool aimed at high school students. The fantastical design with talking muskrats and sea monsters make the place-based simulation a bit unrealistic which may interfere with students transfer of knowledge to real world activities.

Amount of time:
Approximately 30 minutes.

Technology platforms and requirements:
This game requires internet access and a computer using Flash 8. Only devices that are able to download and run flash are able to be used.

Access to student data:
Game developers may have access, but it is a free online game that does not automatically show data. This data may be available from the development team but that is not an option currently. Also, the game has one outcome so the resulting data and solution paths are fairly consistent.

Replayability:
This game is not replayable. This is a story game where you move through a virtual world and interact with non-playable characters and complete tasks. When replaying the game, the storyline and interactions would be nearly identical to the first trial.

Adaptability options:
This game has a specific storyline that restricts adaptations.

Adaptive complexity:
There are no levels of complexity as there is only one version of this game.

Scalability:
This game can be scaled in terms of handling multiple users and multiple states. This game may not be as good at adapting to different grade levels.

Amount of teacher training necessary:
The developers of this game state that it is meant to be implemented as part of a class curriculum so there are teacher resources to go with the implementation. However, from our playing of the game, teacher training does not seem necessary.

Grade Level:
Upper-elementary school and early middle school

The Mystery of Taiga — Quest Atlantis

The Mystery of Taiga River takes place in a 3D immersive world where students become environmental scientists who lead a scientific investigation to save a virtual park with ecological problems causing the fish to die out. The game not only teaches students issues of water quality like pH, turbidity, dissolved oxygen, and nutrient run-off but also presents an innovative way of using a systems-thinking approach to decision-making in a complex community. This curriculum meets Next Generation Science Standards.
https://sashabarab.org/activity/arx-the-mystery-of-taiga-river/

Advantages:
This game is built by a research group and therefore has empirical and theoretical articles supporting their game play. In their theory of transformational play, Barab and associates (2009; 2010) advocate engaging in virtual worlds that allow students to project their identity into the role of an agent in a problem-based activity, known as a quest, where students can learn and apply content in the context of use. Importantly, students acting in the world have the ability to change and transform that world and ideally conceptions of the student themselves. While investigating the problem, students are exposed to ecological content knowledge including concepts such as water quality and eutrophication. During their quest, students "are introduced to what these concepts *mean*, they experience *how* the concepts *have meaning* by making decisions about how to improve water quality" (Barab et al., 2010, p. 529, italics in original). Students engage in a compelling narrative (the quest) and are able to collect data, interact with other students and characters, make decisions, and experience the consequences of their actions. Importantly, virtual worlds like Quest Atlantis can transport students into such world and provide consequentiality in these worlds. That is, actions in these virtual worlds illuminate the consequences of such decisions and offer meaningful decision-making. Worlds such as this offer students the ability to engage in thinking about decision-making, complex systems, and ecology concepts without needing to know how to collect the water samples, therefore affording realistic problem-solving about core disciplinary ideas.

Disadvantages:
Quest Atlantis' storybook nature introduces issues for replayability and customization. Within the game some activities have embedded and automated assessments, however, there are quite a few activities that require using a rubric to score each student's submission. This game also does not seem to be fully supported by the developers as the website has many broken links for teacher support materials. This game also takes a long time to play.

Amount of time:
Approximately 5 to 10 days

Technology platforms and requirements:
This game requires the user to download a 700MB file.

Access to student data:
Game developers may have access, but it is a free online game that does not automatically show data. This data may be available from the developers so not sure if this data is stored by the developers.

Replayability:
This game is not replayable. This is a story game where you move through a virtual world and interact with non-playable characters and complete tasks. When replaying the game, the storyline and interactions would be nearly identical to the first trial.

Adaptability options:
This game has a specific storyline that restricts adaptations.

Adaptive complexity:
There are no levels of complexity as there is only one version of this game.

Scalability:
This game can be scaled in terms of handling multiple users and multiple states. This game may not be as good at adapting to different grade levels.

Amount of teacher training necessary:
The developers of this game state that it is meant to be implemented as part of a class curriculum so there are teacher resources to go with the implementation. However, from our playing of the game, teacher training does not seem necessary.

Grade level:
Elementary and middle school

Web-based Inquiry Science Education (WISE)

The Web-based Inquiry Science Education (WISE) is a free, standards-aligned, and research-based inquiry curriculum that addresses NGSS 3D proficiency. WISE provides interactive scientific models plus hands-on activities, personalized guidance, and rich embedded assessments. This tool provides teachers with robust grading and management tools supporting individualized and customized learning. WISE projects range in duration from 2 days to 4 weeks, providing inquiry topics for teachers in grades 4 to 14.
https://wise.berkeley.edu/

Advantages:
This curriculum has been used in a variety of domains and has many published empirical studies of the curriculum. The description states WISE aligns with national science standards and is an inquiry-based activity. It is also free. The game offers interactive dynamic visualizations, and online critiquing. This game has been researched nationally and internationally with authors publishing theoretical and empirical results about the benefits of this program.

Disadvantages:
One of the main disadvantages is that it is a 3-10 day curriculum that requires teacher training and grading. While it is free and open access, it is not scalable as an assessment because it requires teachers to grade assignments. This introduces many different raters of student work making the assessment less reliable at scale.

Amount of time:
Approximately 3 to 10 days

Technology platforms and requirements:
Online

Access to student data:
Teachers are able to access student data within the WISE system.

Replayability:
Each curriculum does not seem to be replayable as it would provide the same experience as the first trial.

Adaptability options:
The game has been adapted.

Adaptive complexity:
There are no varying levels of complexity as there is only one version of this game.

Scalability:
This curriculum can be scaled in terms of handling multiple users and multiple states. However, the curriculum requires teacher grading which is not scalable.

Amount of teacher training necessary:
Of all of the games in this review, WISE may have the most amount of required training and teacher participation. Teachers need to grade many different pieces of student work.

Grade level:
Elementary, middle, and high school

ONPAR Middle School Science Testlet

The Institute for Innovative Assessment (IIA) pioneers the development and investigation of leading-edge assessment instruments and related resources that support teaching and learning at the classroom, interim, and summative levels. The ONPAR approach to assessment design makes use of dynamic, multi-semiotic representations and carefully constructed stimuli and response spaces to minimize construct-irrelevant text while still targeting cognitively complex content and skills.
http://iiassessment.wceruw.org/projects/ONPAR-science-tasks.html

Advantages:
ONPAR is an experiential and validated assessment where students drag and drop ideas into different parts of a conceptual framework. They currently offer nine different curricula for elementary and middle school students. The assessment is also automated so there is no teacher grading and is currently being used in multiple states (Maryland, Nevada, Oregon).

Disadvantages:
While the assessment is automated and validated the actual right and wrong answers are not transparent. Data is accessible as an end of assessment report but students and teachers are not able to review which questions they got correct or incorrect. The tool currently does not offer replayability, there are no isomorphic problem sets, and there is no adaptive complexity. ONPAR requires teacher training which is a disadvantage.

Amount of time:
The time for completion depends on the thoroughness of students. Most assessments are twelve screens, but some have context and animations. The typical assessment takes 45 minutes.

Technology platforms and requirements:
ONPAR requires an html 5 browser.

Access to student data:
There is no access to student answers to questions; however, there is a validated score report that is provided at the end of the assessment for both students and teachers.

Replayability:
Students are able to retake the assessment; however, it would be identical to the original assessment. One option would be to separate the twelve screens into six or three screen versions of subtopics but this has not been validated.

Adaptability options:
There currently is no option to customize.

Adaptive complexity:
There is no adaptive complexity.

Scalability:
Yes, ONPAR is currently being used in Maryland, Las Vegas, NV, and Oregon

Amount of teacher training necessary:
ONPAR requires that teachers engage in a 45 minute training. There are also user guides, training videos, and other online resources. Overall, these trainings seem minimal.

Grade level:
Elementary and middle school

Local Environmental Modeling System

The Local Environmental Modeling (LEM) toolkit is a web-based simulation in which participants explore the environmental and socioeconomic impacts of land-use decisions. LEM is available via a website and can be accessed on phones, tablets, and computers using any internet browser. The LEM toolkit will allow users to change the geographical location and environmental and socioeconomic issues that learners work within the land-use model.
https://lem.epistemic-games.org

Advantages:
LEM is a place-based, standards-aligned, inquiry-based game that was created using real data. It is easily customized and requires little to no teacher training in order to implement.

Disadvantages:
While this game is based on many sources of real data, this data has been simplified for game play and student understanding. This game is publicly available but still in beta testing. While

this model has been used in classrooms in multiple states, LEM has not tested the tool for fidelity with many students using the tool at the same time.

Amount of time:
About 1 hour

Technology platforms and requirements:
This game requires internet access and a computer, smartphone, or tablet.

Access to student data:
Yes, all data is available.

Replayability :
Students can replay the application in multiple locations and with different problem scenarios.

Adaptability options:
Students can choose different locations and indicators.

Adaptive complexity:
There is no adaptive complexity.

Scalability:
Yes, LEM is currently being used in 2 states (Wisconsin and Massachusetts).

Amount of teacher training necessary:
No training necessary.

Grade level:
Middle and high school

Tool Comparison Summary

The twelve Components of Environmental Literacy and the eleven Technical Requirements were evaluated for all six Tools. A complete chart is available for review (Appendix C). Next we reduced the tool comparisons to a chart with the seven key priorities for technical requirements and components of environmental literacy.

Technical Requirements	**ElectroCity**	**Citizen Science**	**Quest Atlantis**	**WISE**	**ONPAR**	**LEM**
Data Access	No	No	No	Yes	Yes	Yes
Scalability	No	Yes	Yes	No	Yes	Yes
Teacher Training Required	No	No	Yes	Yes	No	No
Components of Environmental Literacy						
Think Critically	Yes	Yes	Yes	Yes	Yes	Yes
Recognize +/- Consequences	Yes	No	Yes	Yes	No	Yes
Informed Planning	Yes	No	Yes	Yes	No	Yes
Identify Problems	Yes	Yes	Yes	Yes	No	Yes

In this chart, the only component that is included in all tools is Think Critically. Some tools are able to achieve all components of Environmental Literacy but only one technical requirement (e.g. ElectroCity, Quest Atlantis, WISE). Citizen Science meets two of each. This result is interesting in the sense that there are tools that are strong in meeting literacy components but not the technological requirements, or the opposite.

Using the tool comparison, we are able to capture important tradeoffs in tools. In the end, only the LEM and ONPAR are able to meet all technical requirements. Although ONPAR met the technical requirements, ONPAR met the fewest environmental literacy components of all tools. While ONPAR could be modified to include identifying problems, we believe it would be too difficult to modify ONPAR to be able to include informed planning and recognizing consequences. Further, ONPAR was designed to not include any writing, which may reduce opportunities for critical thinking and reflection.

Final Project Analysis: Tool Recommendations

In conclusion, LEM is the only tool that meets all of the tool requirements as well as environmental literacy components requirements. Each of the other five tools would require massive adaptations to meet the core requirements in addition to adaptations for the tool to meet the full list of tools specifications and literacy components.

Tool Modifications

That being said, we believe that we would need to modify LEM to meet the components and underlying activities for environmental literacy. While the LEM met all literacy and technical requirements, LEM currently does not address reflection and taking action.

First, we would need to add mechanisms to gather more explicit reflection data where students provide a more explicit explanation for the reasons behind their actions. This would require developing additional pop-up mechanisms and prompts that ask students to reflect on the actions they take in the tool. These explanations would allow LEM to achieve the "reflect" category from the environmental literacy components. These reflections would also allow LEM to meet the specific Environmental Literacy Activities from previous discussions. By adding reflections and justifications, LEM can provide students opportunities to meet each of the evaluation activities (e.g. evaluate an environmental issue using data and draw a conclusion, evaluation their problem-solving process) as well as increase the effectiveness of other activities (e.g. identify and define an environmental problem, students reflection on the relationship between their attitudes and choices on the environment). One example of such a modification would be to add a mechanism that identifies a student engaging in an experiment where they change a single parcel to each of the different land uses. Kira, the virtual mentor, might pop up and ask, "Before we go on, how do you think zoning affects the indicators?" Or at the time of map submission, Kira might say, "Before I submit your proposal, can you please explain your approach to map changes?"

Second, the LEM currently does not allow students to show their intention to take real world action. LEM could add an Environmentally Responsible Behavior survey to assess current and future behaviors.

Validation Studies

While LEM may be a useful tool for identifying student decision-making and changes in learning, there is a difference in making claims about learning activities and making claims about student literacy at scale. Often LEM is used in informal settings as a way to teach students about the tradeoff in eco-social problems using model-based reasoning. This is a low risk use with few consequences for teachers and students. On the other hand, assessing student literacy at scale is a high risk, high impact, and consequential usage of a tool. For this

reason, LEM or any other assessment tool should complete validation studies before deploying in classrooms.

Validation studies check to make sure that assessments are not systematically biased in some way that may provide privileges to some students or disadvantages to others. Validation studies also check for the assessment for various types of validity. We would want to ensure that there are no threats to construct validity - that is, that our assessment tool has the ability to make inferences about unseen traits such as environmental literacy. We would want to make sure that the tool has strong face validity to ensure that stakeholders believe it measures what it is supposed to measure. Additionally, we would want to ensure the LEM tool has good ecological validity by making sure the assessments correlates with other external measures or expert ratings of Environmental Literacy.

Conclusion

The development of an environmentally literate populace is critical. The move to develop an authentic and validated assessment tool for environmental literacy is no easy task. To date there are few methods to assess one's level of environmental literacy, and they have been debated by scholars and practitioners alike. However, there are many issues to consider when understanding all that environmental literacy means. No one has developed a systematic and authentic assessment tool to address environmental literacy that is game-based. The opportunity for Rhode Island Environmental Education Association, in partnership with Mass Audubon and EF Games, LLC. to become pioneers in this work for the larger environmental education community is significant with the necessary financial resources.

Based on the work of the AEL project, we conclude that developing an authentic game-based assessment tool is possible when the targeted components of environmental literacy are pulled out, the requirements of the assessment tool are identified, and a gaming platform is properly vetted. For the purposes of the AEL project, LEM was identified as the tool with the highest potential for the development of an assessment of environmental literacy with future game modifications and validations.

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Appendices

Appendix A

Learning Outcomes by Source

This chart includes Sources 2-11 from the Literature Review section of this report.

Topics	Hollweg et al. (2011)	Marcinowski (2019)	McBride et al. (2013)	Hunter (2016)	RIEEA Wrkshp (2019)	Ardoin et al. (2017)	McBeth (2014)	Minner & Klein (2016)	EPA (2019)	NGSS (2013)
Environmental sensitivity	■	■	■			■	■		■	
Environmentally responsible behavior		■		■	■	■	■			
Knowledge about physical ecosystems	■		■				■	■		
Analyzing environmental issues	■	■			■					■
Identifying environmental issues	■	■	■						■	
Attitudes and values associated with nature		■				■	■		■	
Locus of Control	■		■	■						
Personal responsibility	■	■			■					
Knowledge about environmental issues	■		■						■	
Knowledge about sociopolitical issues	■		■			■				
Developing possible solutions	■								■	■
Evaluate issues and potential solutions	■	■								■
Investigating environmental issues		■			■					■
Intention to act	■					■	■			
Beliefs				■		■				
Interest	■					■				
Self-efficacy		■			■					
Content knowledge				■		■				
Knowledge of problems and solutions		■								■
Analyzing and interpreting data		■								■
Collecting information					■					■

Defining environmental problems										
Planning and carrying out investigations										
Affect										
Perceptions										
Active participation in problem solving										
Participate in action planning for themselves and their community to address environmental issues										
Participation in activities that lead to the resolution of environmental challenges										
Participation in various problems and issues in the community, county, state, national.										
Willingness to serve/act										
Character development										
Recognizing efficacy and developing agency										
Self-esteem										
Knowledge of issue resolution and social change strategies										
Knowledge of natural history and ecology										
Knowledge of service/action strategies available										
Skills knowledge										
Biodiversity and Humans										
Context: local, regional, and global situations that involve the environment										
Ecosystem Dynamics, Functioning, and Resilience										
Global Climate Change										
Human Impacts on Earth Systems										

Human systems (especially individuals, groups, and societies)										
Human-environment										
Issue-specific understanding										
Natural hazards										
Natural resources										
Weather and climate										
Asking questions and defining problems										
Cognitive competencies										
Constructing explanations and designing solutions										
Decision-making and action skills										
Defining engineering problems										
Developing and using models										
Engaging in argument from evidence										
Environmental issue and action skills										
Field/lab skills used in monitoring problems, and analyzing and interpreting data on problems and studies of nature										
Obtaining, Evaluating, and Communicating Information										
Propose and justify actions to address environmental issues										
Skills										
Social competencies										
Strategies for addressing issues										
Think critically about how human actions affect ecological functioning and subsequent environmental issues/problems that arise										

Using mathematical and computational thinking										
Appreciate natural phenomena and biodiversity through observation and direct experiences in natural settings										
Attitudes of concern for the environment and motivation to improve or maintain environmental quality										
Environmental concerns or attitudes, and values associated with problems and issues.										
PatternsCCC										
Cause and EffectCCC										
Scale, proportion, and quantityCCC										
Systems and system modelsCCC										
Energy and matterCCC										
Structure and functionCCC										
Stability and changeCCC										

Appendix B

Components of EL by Skive

In the SKIVE column of the chart, the numbers refer to the Literature Review documents (2 = Hollweg, 3 = Marcinowski, etc… [Source 1 is not listed as it was the draft concept map and so did not inform the Topics])

Components of Environmental Literacy	SKIVE	Activities
Interpret & Analyze Data	Skill: Analyzing and interpreting data,3,11 Skill: Analyzing environmental issues,2,3,6,11 Skill: Developing and using models,11 Skill: Field/lab skills used in monitoring problems, and analyzing and interpreting data on problems and studies of nature,3 Skill: Investigating environmental issues,3,6,11 Skill: Planning and carrying out investigations,3,11 Skill: Using mathematical and computational thinking,11 Skill: PatternsCCC,11 Skill: Scale, proportion, and quantityCCC,11 Skill: Systems and system modelsCCC,11 Epistemology: Asking questions and defining problems,11 Epistemology: Evaluate issues and potential solutions,2,3,11 Epistemology: Using mathematical and computational thinking,11	Evaluate an environmental issue using data and draw a conclusion; Use a model to identify patterns within an environmental system; Conduct an experiment to gather data

Think Critically	Skill: Active participation in problem solving,4 Skill: Analyzing environmental issues,2,3,6,11 Skill: Asking questions and defining problems,11 Skill: Constructing explanations and designing solutions,11 Skill: Developing and using models,11 Skill: Investigating environmental issues,3,6,11 Skill: Planning and carrying out investigations,3,11 Skill: Think critically about how human actions affect ecological functioning and subsequent environmental issues/problems that arise,9 Skill: Cause and EffectCCC,11 Skill: Systems and system modelsCCC,11 Knowledge: Strategies for addressing issues,2 Epistemology: Context: local, regional, and global situations that involve the environment,2 Epistemology: Defining engineering problems,11 Epistemology: Engaging in argument from evidence,11 Epistemology: Evaluate issues and potential solutions,2,3,11 Epistemology: Strategies for addressing issues,2 Epistemology: PatternsCCC,11 Epistemology: Context: local, regional, and global situations that involve the environment,2 Epistemology: Defining engineering problems,11 Epistemology: Engaging in argument from evidence,11	Evaluate an environmental issue using data and draw a conclusion; Use a model to identify patterns within an environmental system; Conduct an experiment to gather data; Investigate how the local context affects the environmental problem

	Epistemology: Evaluate issues and potential solutions,2,3,11 Epistemology: Strategies for addressing issues,2 Epistemology: PatternsCCC,11	
Construct Justification	Skill: Obtaining, Evaluating, and Communicating Information,11 Epistemology: Constructing explanations and designing solutions,11 Epistemology: Engaging in argument from evidence,11 Epistemology: Propose and justify actions to address environmental issues,2	Use data to explain the reasons behind a decision
Recognize +/- Consequences	Skill: Evaluate issues and potential solutions,2,3,11 Skill: Think critically about how human actions affect ecological functioning and subsequent environmental issues/problems that arise,9 Skill: Cause and EffectCCC,11 Skill: Stability and changeCCC,11	Evaluate how human decisions change environmental systems
Informed Planning	Skill: Participate in action planning for themselves and their community to address environmental issues,9 Skill: Constructing explanations and designing solutions,11 Skill: Developing possible solutions,2,10,11 Skill: Evaluate issues and potential solutions,2,3,11 Skill: Planning and carrying out investigations,3,11 Knowledge: Strategies for addressing issues,2 Identity: Locus of Control,2,4,5 Values: Attitudes and values associated with nature,3,7,8,10 Values: Attitudes of concern for the environment and motivation	Evaluate an environmental problem; Design a plan to address this environmental problem; Then evaluate the problem and solution

	to improve or maintain environmental quality,10 Epistemology: Evaluate issues and potential solutions,2,3,11 Epistemology: Propose and justify actions to address environmental issues,2	
Take Action	Skill: Participation in activities that lead to the resolution of environmental challenges,10 Skill: Participation in various problems and issues in the community, county, state, national.,3 Skill: Environmental issue and action skills,8 Skill: Planning and carrying out investigations,3,11 Identity: Willingness to serve/act,3 Identity: Locus of Control,2,4,5 Identity: Recognizing efficacy and developing agency,6 Identity: Intention to act,2,7,8 Values: Environmentally responsible behavior,3,5,6,7,8 Epistemology: Environmentally responsible behavior,3,5,6,7,8	
Reflect	Skill: Asking questions and defining problems,11 Skill: Decision-making and action skills,6 Skill: Evaluate issues and potential solutions,2,3,11 Identity: Recognizing efficacy and developing agency,6	Evaluate their problem-solving process

Gather Information	Skill: Collecting information,6,11 Skill: Developing and using models,11 Skill: Field/lab skills used in monitoring problems, and analyzing and interpreting data on problems and studies of nature,3 Skill: Investigating environmental issues,3,6,11 Skill: Obtaining, Evaluating, and Communicating Information,11 Skill: Planning and carrying out investigations,3,11 Knowledge: Field/lab skills used in monitoring problems, and analyzing and interpreting data on problems and studies of nature,3 Epistemology: Obtaining, Evaluating, and Communicating Information,11	Students gather and organize environmental data
Empathy	Skill: Participate in action planning for themselves and their community to address environmental issues,9 Skill: Appreciate natural phenomena and biodiversity through observation and direct experiences in natural settings,9 Identity: Willingness to serve/act,3 Identity: Character development,7 Identity: Locus of Control,2,4,5 Identity: Personal responsibility,2,3,6 Values: Willingness to serve/act,3 Values: Beliefs,5,7 Values: Interest,2,7 Values: Affect,5,7 Values: Attitudes and values associated with nature,3,7,8,10	Students engage in perspective-taking and work to balance multiple perspectives; Students reflect on the relationship between their attitudes and choices on the environment; Students take actions and see consequences on the environment

	Values: Attitudes of concern for the environment and motivation to improve or maintain environmental quality,10 Values: Environmental concerns or attitudes, and values associated with problems and issues.,3 Values: Environmental sensitivity,2,3,4,7,8,10 Values: Intention to act,2,7,8 Values: Perceptions (attitudes and beliefs) ,4,7	
Self-Efficacy	Identity: Locus of Control,2,4,5 Identity: Recognizing efficacy and developing agency,6 Identity: Self-efficacy,3,6	Engage in problem-solving where students are able to solve increasingly complex problems over time

Explicit Environmental Domain Knowledge	Skills knowledge,7 Skill: Constructing explanations and designing solutions,11 Content knowledge,5,7 Knowledge about environmental issues,2,4,10 Knowledge about physical ecosystems,2,4 Knowledge about sociopolitical issues,2,4,7 Knowledge of issue resolution and social change strategies,3 Knowledge of natural history and ecology,3 Knowledge of problems and solutions,3,10 Knowledge of service/action strategies available ,3 Skills knowledge,7 Knowledge: Context: local, regional, and global situations that involve the environment,2 Knowledge: Ecosystem Dynamics, Functioning, and Resilience,11 Global Climate Change,11	Investigate an environmental problem (not all knowledge components may be met and will depend on context of chosen problem)

	Knowledge: Human Impacts on Earth Systems,11 Knowledge: Human systems (especially individuals, groups, and societies),6 Knowledge: Human-environment,6 Issue-specific understanding,7 Knowledge: Natural hazards; Natural resources; Weather and climate; Biodiversity and Humans; 11 Knowledge: Appreciate natural phenomena and biodiversity through observation and direct experiences in natural settings,9 Knowledge: Attitudes and values associated with nature,3,7,8,10 Knowledge: Attitudes of concern for the environment and motivation to improve or maintain environmental quality,10 Knowledge: Environmental concerns or attitudes, and values associated with problems and issues.,3	
Identify Problems	Skill: Defining engineering problems,11 Skill: Defining environmental problems,4,11 Skill: Identifying environmental issues,2,3,4,10 Values: Environmental concerns or attitudes, and values associated with problems and issues,3 Epistemology: Defining engineering problems,11 Epistemology: Defining environmental problems,4,11 Epistemology: Environmental concerns or attitudes, and values associated with problems and issues,3	Identify and define an environmental problem

Appendix C

Tool Comparison Chart (entire)

Technical Requirements	**ElectroCity**	**Citizen Science**	**Quest Atlantis**	**WISE**	**ONPAR**	**LEM**
Time	30 minutes	1-2 Hours	5-10 Days	3-10 Days	10-30 minutes	1 hour
Platforms	No longer available	Flash, may not be available	700 MB download	Web	Web	Web
Data Access	No	No	No	Yes	Yes	Yes
Replayability	Yes	No	No	No	No	Yes
Customizable	No	No	?	Yes	?	Yes
Adaptive Complexity	No	No	No	No	No	No
Scalability	No	Yes	Yes	No	Yes	Yes
Teacher Training Required	No	No	Yes	Yes	No	No
Elementary School	No	No	Yes	Yes	No	No
Middle School	Yes	Yes	Yes	Yes	Yes	Yes
High School	Yes	Yes	No	Yes	Yes	Yes
Components of Environmental Literacy	ElectroCity	Citizen Science	Quest Atlantis	WISE	ONPAR	LEM
Interpret and Analyze Data	Yes	Yes	Yes	Yes	Yes	Yes
Think Critically	Yes	Yes	Yes	Yes	Yes	Yes
Construct Justification	No	Yes	Yes	Yes	Yes	Yes
Recognize +/- Consequences	Yes	No	Yes	Yes	No	Yes
Informed Planning	Yes	No	Yes	Yes	No	Yes
Intention to Take Action	No	No	No	No	No	No
Reflect	No	No	Yes	Yes	No	No
Gather Information	Yes	Yes	Yes	Yes	No	Yes
Empathy	Yes	Yes	Yes	No	No	Yes
Self-efficacy	Yes	Yes	Yes	Yes	Yes	Yes
Explicit Domain Knowledge	No	Yes	Yes	Yes	Yes	Yes
Identify Problems	Yes	Yes	Yes	Yes	No	Yes