Received: 24 September 2019 | Accepted: 28 January 2020
DOI: 10.1002/nse2.20005

Natural Sciences Education

ORIGINAL RESEARCH ARTICLE
K–12 Education

# Alignment of a digital watershed and land use game to national education standards

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**Funding information**
Iowa State University Departments of Natural Resource Ecology and Management; Agricultural Education and Studies; Agronomy USDA McIntire-Stennis Program, Grant/Award Numbers: IOW5423, IOW5534

**Abstract**

Digital games, especially simulations, have supported student learning outcomes in the areas of science and agriculture in classrooms and nonformal settings. Simulations contribute robustly to student achievement in science, technology, engineering, and mathematics (STEM), and agriculture content areas, especially when they are aligned with national education standards. The People in Ecosystems Watershed Integration (PEWI) simulation is a digital game that was evaluated for fit to two national standards: the Next Generation Science Standards (NGSS) and the Agriculture, Food, and Natural Resources Standards (AFNR). The evaluation of alignment of PEWI to NGSS provided "extensive" evidence on a four-point scale for meeting Criterion A: Explaining phenomenon/designing solutions; Criterion B: 3-D learning, science and engineering practices, rated for three areas: (a) "extensive" for science and engineering practices, (b) "adequate" for disciplinary core ideas, and (c) "extensive" for cross-cutting concepts. Additionally, PEWI aligned with nine high school–level NGSS student performance expectations categories. For AFNR Standards, the PEWI evaluation provided evidence for alignment to 10 standards and 17 indicators from the AFNR areas of Environmental Service Systems, Natural Resource Systems, and Plant Systems.

## 1 | INTRODUCTION

Computer games enlarge the pool of curriculum materials for teachers, 4-H, and community leaders who facilitate education with learners from youth to adult. Digital game-based learning (DGBL) includes commercially produced games but excludes those rated for violence or other warned content. The DGBL games nearly always offer, however, "entertaining power…to serve an educational purpose…a balance between learning and gaming elements" (All, Castellar, & Van Looy, 2016, p. 91). Games are not a new element in teaching and learning; board games, case studies, role play situations, and other "serious games" have been available to teachers for decades (Rodela, Ligtenberg, & Bosma, 2019). Computer games have been used in classrooms by 80% of middle and high school teachers, according to An, Haynes, D'Alba, and Chumney (2016). It is the digital element and its relationship to learning that calls for greater attention.

**Abbreviations:** AFNR, Agriculture, Food, and Natural Resources; DGBL, digital game–based learning; NGSS, Next Generation Science Standards; PEWI, People in Ecosystems Watershed Integration; STEM, science, technology, engineering, and mathematics.

This article focuses on the fit of a university-created digital game, People in Ecosystems Watershed Integration (PEWI) (Natural Resource Ecology and Management, 2019, 2020) to two national education standards for high school science and agriculture. Curricula that hew more closely to education standards have a greater potential to contribute to student achievement (Fulmer, Tanas, & Weiss, 2018). As part of our review, we highlighted elements that characterize adoption issues by classroom teachers and discuss features of games that comprise high-quality DGBL.

**Core Ideas**

- Digital game-based learning (DGBL) contributes to learning in agriculture and science.
- Simulations are an important type of digital game used by teachers.
- PEWI is an educational watershed and land use simulation game.
- PEWI aligns with selected national science and agriculture high school standards.

## 1.1 | Schools and digital access

Schools in many regions provide ready access to computers and the internet, but access remains insufficient in some communities, including on rural tribal lands (Congressional Research Service, 2019). In our largely rural and agricultural state (Iowa), the student/computer ratio in public schools reached 1:1 in 2017 (Iowa Department of Education, 2018, p. 91), providing greater justification for use of DGBL units in classrooms.

Less clear, however, is whether the level of resources for professional development for teachers is broadly sufficient to attain mastery with DGBL curricula. Administrators may schedule professional development for district or building-wide administrative software updates, but less frequently for grade-band or content area DGBL curricula. A study of middle and high school teachers by An et al. (2016) identified lack of preparatory and lesson planning time, and noted limited support for integration of games into the curriculum, as barriers to adoption and best use. Yoon, Goh, and Park (2018) emphasized the importance of additional preparation of teachers about complex science concepts when integrating new curricula, digital or otherwise, into the classroom.

## 1.2 | Indicators of quality

### 1.2.1 | Serve the curriculum

Foremost in the minds of teachers is the need for computer games to fit the curricula, such as learning objectives; district-wide outcomes; and state, professional, and national guidelines. Bourgonjon et al. (2013) reported that secondary school teachers observed that commercial DGBL products—the products most likely to be used in classrooms—frequently failed to match subject matter, student age range, and other key criteria. A study by Rutten, van Joolingen, and van der Veen (2012) demonstrated that different levels of integration of simulation software affected the degree to which college students achieved course objectives in a quasi-experimental study of a physics laboratory session. Their study underscored the value of a close match of curricular goals with DGBL products. In science and agriculture, the availability of appropriate games appears to be insufficient.

### 1.2.2 | Features

Recent studies documented the success of features that belie some of the myths about games generally held by society. For example, All et al. (2016) concluded that games that were simple and quickly completed did not contribute as much to content learning as games that were longer, more complex, and required more effort. Moreno, Mayer, Hiller, Spires, and Lester (2001) documented the role that students' DGBL active participation played in a plant physiology game on knowledge retention, and transfer of knowledge. Greater participation, which required greater effort, earned greater achievement.

### 1.2.3 | Features for motivation

Studies have also addressed motivation, which plays a role in persistence and may increase achievement of any number of types of learning. Strongly associated in popular culture regarding games are reward features (e.g., badges, tokens, points). Teachers recognize reward systems as behaviorist token economy systems, which have been used in American schools since the mid-20th century. Although rewards are widely recognized as part of computer games' allure, they contribute only moderately to knowledge retention, and rarely account for the entirety of a game's success (Bellotti, Kapralos, Lee, Moreno-Ger, & Berta, 2013).

Some scholars argue that text or verbal prompts and feedback assistance, including use of avatars or interactive pedagogical agents, are superior to rewards when users are stuck, and surpass rewards for enhancing continued play, which contribute to overall achievement (Law & Chen, 2016; Moreno et al., 2001). When combined with rewards, these additional motivational features together appear to support cognitive and other gains more handily (Bellotti et al., 2013). There does not appear to be a single feature that wins the day, but a combination.

The construct of "flow," or engagement, also appears to play a strong role in motivation to continue to play (Bellotti et al., 2013). This phenomenon is a consequence of scaffolding of game levels, complexity, and well-placed challenges (Hamari et al., 2016). The best games are described as having excellent flow and engagement.

### 1.2.4 | Text environment

Some digital units mainly provide a text environment (Moreno et al., 2001). By using the term "text," we indicate that reading matter is shown on the screen. Text may be interspersed with puzzles, videos, or audio prompts. Alone or with enhancements, a text environment engenders passive learning, akin to reading a textbook. To the extent that reading is the preferred task, a text environment may be suitable for a learning context and a "gamified" structure for reading may be set, but it is generally not considered to be DGBL.

### 1.3 | Evidence of learning

Teachers assess potential cognitive, affective, and psychomotor contributions to learning when weighing new additions to the curriculum. A game, like other lessons or units, would need to deliver outcomes clearly and consistently.

Cognitive gains are the most frequently sought type of learning outcome assessed in the literature. Bellotti et al. (2013) noted that most studies examined lower levels of cognition, such as memorization of content. They argued, further, that the literature as a whole emphasized successful delivery of lower levels of cognitive performance because most studies were designed to test lower levels. Higher levels of cognition include critical thinking or evaluative thinking and could be included in more studies.

Some studies assessed dimensions outside of, or in addition to, cognition. Connolly, Boyle, MacArthur, Hainey, and Boyle (2012) provided a meta-analysis of 129 DGBL studies that measured, among them, affective dimensions, including motivation, motor skills, perceptual skills, behavior change (i.e., willingness to collaborate), and physical changes (i.e., blood pressure), in addition to levels of cognition. The most frequently occurring outcomes remained "knowledge acquisition/content understanding." Affective and motivational items were examined mainly for games that were designed for entertainment (Connolly et al., 2012).

## 2 | SUMMARY OF PEWI FEATURES

In PEWI, students' main tasks are to develop and test goals, select and change land uses, and determine effects of decision making. When the student sets a goal, and then changes a land use selection, size, or placement, it instantaneously alters biological, chemical, and crop production indicators in the game. The main screen in PEWI features a large watershed with a river (the PEWI River) running north to south (Figure 1). PEWI is built around realistic land uses and land formations in the U.S. Midwest (Prior, 1991). Learning outcomes are based on functions of specific soil types, typography, and the tradeoffs associated with land use choices. Students are shown impacts of their logic and choices on water quality, biodiversity, and farm production.

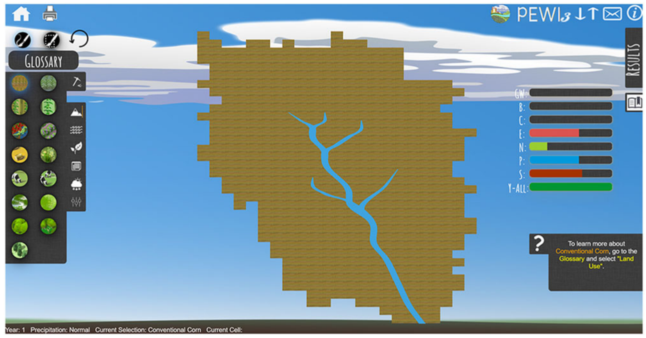


**FIGURE 1** The People in Ecosystems Watershed Integration (PEWI) watershed (brown center), with the PEWI River running north to south (blue, center). Glossary tab and land use selections (left), Ecosystem service indicators (right hand bars), Results tab (upper right), and other function tabs

### 2.1 | Audiences for PEWI

This article, with the analysis of the alignment of PEWI to education standards, focuses on school-based learning for high school students in science and agriculture courses. PEWI has been used for additional audiences, however, from middle school students to college students. PEWI also fits nonformal contexts, such as 4-H and science fair applications. The game accomplishes this breadth through the application of features that can be turned off, such as precipitation, which can be held constant across years and users, and by limiting the number of land uses or maps. PEWI allows students to create color printed posters of the watershed and Results and data visualization for presentation of unique student work, which fit applications required of 4-H and science fairs.

#### 2.1.1 | Teachers Guide

We created an online Teachers Guide that is hosted on Canvas, a digital Learning Management System. The Teachers Guide provides lesson plans; brief videos (1–3 minutes) for game tutorials, with text; videos about creating PEWI; science,

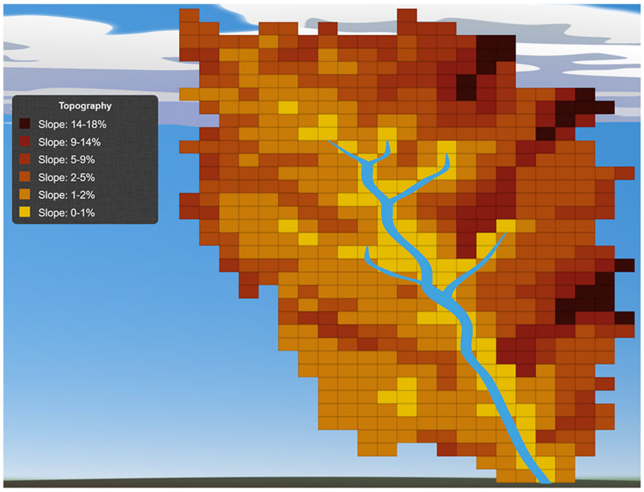


**FIGURE 2** The People in Ecosystems Watershed Integration (PEWI) watershed showing topography (slope). Legend to the left. PEWI River running north to south. Students can toggle to show the map before placement of land uses

technology, engineering, and mathematics (STEM) career videos; standards alignments tables; guides to 4-H projects and fair submissions; an interactive discussion board; site contacts; and lists of other DGBL resources.

# 3 | THE PEWI WATERSHED

## 3.1 | Nearly 6,000 acres and 15 land uses

The PEWI game simulates a watershed that consists of 5,888 acres (2,382 ha) with geophysical features combined from two Iowa landforms, the Des Moines Lobe and the Southern Iowa Drift Plain (Prior, 1991). Fifteen land uses can be applied or removed, including: corn (two planting systems), soybean (two planting systems), mixed fruits and vegetables, alfalfa, grass hay, cattle (two pasture systems), wetlands, prairie, forest, and woody bioenergy. PEWI provides maps for students to understand and explain differential movement of water, nutrients, and sediment, and comparative growth of vegetation. Maps show historical flood frequency, and sub-watershed boundaries, soil drainage class, soil type, topography, and crop yields. Instructors may set precipitation at seven levels from dry (24.58 inches or 62.43 cm) to wet (45.10 inches or 114.55 cm) or to permit random assignment (Figure 2).

A results table provides numerical scores instantaneously that represent science-based impacts of land use type, placement, and amount. The user may view results as a running slide, in numerical tabular form, or as color data visualizations (Figure 3. Impacts are available for game wildlife and biodiversity, soil quality (including erosion control, gross erosion,

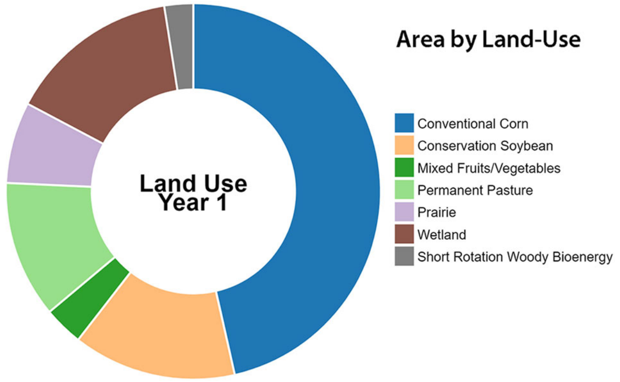


**FIGURE 3** Sample graphic from results data visualization section. Land use areas for Year 1 for student input onto watershed. Shows visually the proportion of land uses. The numerical data is provided in tabular from using a toggle feature. Only land uses that the student used are listed

and carbon sequestration), water quality (including nitrate contamination, nitrate pollution control, phosphorus contamination, and phosphorous pollution control, sediment load, and sediment pollution control), and yield for each land use.

Teachers have used PEWI as a science and agriculture unit related to water quality, flooding and drought, watershed policy, agricultural conservation, agriculture and wildlife, tradeoffs by agricultural communities, watershed improvement, and general soils and crops.

## 3.2 | Characterizing PEWI as DGBL

### 3.2.1 | Content

Content about science and agriculture concepts is important to understanding the simulation. PEWI provides a glossary to provide students with land use concepts used in the game. Some of the concepts are general, but some are specific to production agriculture, such as "conservation corn." The 110 glossary entries are accessed on demand in three modes: text, 1-minute YouTube videos, with audio. The glossary, however, is limited to items necessary for students to interact with PEWI. Additional text and visuals to support student memorization and comprehension of a content area would be provided by the teacher, as the curricula demanded. We consider that the amount of text in PEWI places it outside of the definition of "text environment" type of digital multimedia.

### 3.2.2 | Simulation

The PEWI game is a simplification of real-world patterns and processes (in this case, land uses and watersheds) in a virtual setting, and provides feedback on input, which places it in the category of simulation. Students interact with the game by making predictions and decisions, and then by taking actions that generate meaningful outcomes in an educational environment. Most students make multiple "guesses" to arrive at a satisfactory solution. Multiple iterations in this context are not viewed as a problem but as a way for students to mimic the working behaviors of scientists and engineers. Learners are able to change inputs (hone their ideas) based on the results to meet different goals, or to test revised ideas, for a fully dynamic interaction. These descriptions fit a NGSS science practice definition of "trying things again and again, but without real materials" (National Research Council, 2012). The PEWI thus functions as inquiry-based or experiential learning (Chennault et al., 2016).

Digital game–based learning simulations are preferred by teachers (Connolly et al., 2012) because they allow students to "safely and cost-effectively acquire skills and attitudes which are hard to get by rote learning" (Bellotti et al., 2013, p. 2). Yoon et al. (2018) conducted a meta-analysis of 75 studies over 20 years about teaching and learning about complexity in science. Their study showed that simulations contributed strongly to areas of learning such as assisting students to grapple with concepts such as (a) "inputs/outputs or initial conditions" in the "processes" concept area; and (b) "equilibrium/stability" in the "states" concept area, which were lacking classrooms and laboratories (p. 307). These concepts were considered difficult to teach otherwise.

#### 3.2.3 | Classroom instruction

Considered to be a unit, PEWI spans two or more class sessions, depending on the curricular goal. Teachers may differentiate instruction by altering settings within PEWI to assist all students. As with most features of DGBL, simulation elements can be paired with instructional approaches such as collaborative and team-based learning, as well as lecture, laboratory, and field trips. Annetta (2008) analyzed games that required multiplayer avatars in an educational setting and showed the role that collaboration played in enhancing learning from simulation games. Teachers may combine language arts units that depend on argumentation and writing by asking students to compare scenarios and reflect on community needs; and distinguish tradeoffs among human, ecological, and physical impacts of land use decisions (Chennault et al., 2016). Case study–based lessons can provide opportunities for discussion, argumentation, and writing-based activities and assessments.

## 4 | SIMILAR GAMES

Other DGBL units serve STEM and agriculture. *Rock Your Watershed!* (Water Rocks, 2020) is a unit that is part of a statewide youth water education campaign that addresses non-point source pollution from 10 land parcels, including agriculture and lawns. The game is brief, but a user may repeat the game to raise their score. The game appeals to middle school and high school students. *Cornucopia* (California Academy of Science, 2020) is directed toward grades 5–12. The game is a colorful "fast-paced farm simulation" that focuses on one season of a plot of land. *Cornucopia* provides links for Plan a Field Trip, Resources, and Professional Development. The *Smartscape Decision Support System* (Wisconsin Energy Institute, 2015) provides an online modeling tool for predicting the "economic and environmental" results of "land use transformations." The audience is professional adult. *Journey 2050* is an educational game that focuses on how to "feed 9 billion people by 2050" (Nutrien, 2020) and is associated with Agriculture in the Classroom outreach organizations. The unit offers a Teacher Experience tab with lesson plans and guides. There are multiple games and videos for different levels, timed challenges for solving puzzles, and colorful elementary to middle school student style animation. *NOVA Evolution Lab Game* (WGBH Educational Foundation, 2020) is a "lab and a lesson" for grades 6–12, with links to a Lesson Plan, Procedures, Support Materials, and Standards for teachers.

## 5 | THE PEWI GAME AND EDUCATION STANDARDS

### 5.1 | NGSS and AFNR

Two national education standards are currently pertinent to almost all high school science and agriculture teachers:

- Next Generation Science Standards (NGSS) (National Research Council, 2012, 2013)
- Agriculture, Food and Natural Resources (AFNR) Career Content Standards (National Council for Agricultural Education, 2015)

Education standards are policies intended to improve school and student outcomes, structure professional development of teachers, enhance educational opportunities for students, and specify the nature of accountability. The history of standards for science and agriculture education is long. Fulmer et al. (2018) provide an overview of science education standards in the United States. Their review shows trends across eras and describes the way in which state and national policies have created distinct frameworks over time. They made us aware of differences between NGSS and AFNR, and current state endeavors. We pursued alignment with national standards rather than a particular state or states because PEWI, as a no-cost online game, has been available internationally since its inception.

The NGSS (National Research Council, 2013) is a set of standards for grades K–12 that was created by a consortium of professionals representing 26 states, 41 experts in science education, and was refined with feedback by science teachers. Achieve, Inc. continues to play an active role in development of support materials and assessment protocols for curricula that fit the NGSS design framework (National Research Council, 2013).

The AFNR standards articulate outcomes for programs of study for eight agricultural career cluster areas (National Council for Agricultural Education, 2015). The standards were developed by the National Council for Agricultural Education in association with 11 key organizations, including the FFA Foundation, the National Association of Agricultural Educators, and the Association for Career and Technical Education. AFNR was designed to "crosswalk" with five other standards, including NGSS; consequently, there is overlap and coordination between these two sets of standards.

The AFNR career cluster is 1 of 16 career clusters that provide state-level agricultural education leaders and educators with guidance for students with respect to how students should be able to perform after completing a Program of Study in each career pathway. The AFNR framework functions as a guide to developing Programs of Study broadly and also for individual students. The AFNR plays an important role in bridging secondary and postsecondary institution programs. Within the AFNR career cluster, eight career pathway Content Standards include agribusiness, animal, biotechnology, environmental service, food products and processing, natural resources, plant, and power structural and technical systems. The career clusters structure opportunities for learners to discover interests while guiding them toward future educational pathways through courses, educational, and club activities.

## 6 | METHODS

For both standards, we convened a review team of five individuals who had played roles in programming PEWI, using PEWI in middle school through adult education settings, including some who had taught in middle school through adult education settings in agriculture. Two held teaching licenses (Iowa and Michigan) with endorsements in agriculture and biology.

For both standards, we narrowed the alignment to grades 9–12. The alignment process differed in several ways for NGSS and AFNR, due to definitions, requirements, and rubrics associated with the standards governing body. We therefore provided separate methods and analysis. Findings of the alignment evaluation are provided in the tables. For clarity in some sections, we provide examples from lesson plans.

### 6.1 | NGSS

The NGSS alignment assessment process is extensive and comprehensive and, during the period of our evaluation, was consolidated under a process facilitated by Achieve, Inc. We used processes that combined the *EQuIP Rubric for Lessons and Units: Science (V. 3.0)* (NGSS Lead States, 2016) with Performance Expectations (i.e., student learning objectives) for grade-band 9–12 (Achieve, Inc., 2017). We focused our analysis on Part I: NGSS 3-D Design (A, B) to respond to the NGSS concept of Phenomenon. We excluded II (NGSS Instructional Supports) and III (Monitoring Student Progress) because these vary more by state, building, or classroom. We applied the four-point rubric rating scale (1, *none*; 2, *inadequate*; 3, *adequate*; 4, *extensive*) (p. 6) for NGSS 3-D Design A and B (i, ii, and iii).

### 6.2 | Criterion A: Phenomenon

**Explaining phenomenon/designing solutions. Rated: extensive (4/4).** The term *phenomenon* emphasizes the need for a lesson or unit to be engaging, comprehensive, and connected to the life of the student (Penuel & Bell, 2016). We determined that PEWI has the potential to be sufficiently complex, and to engage emotions and to catalyze discussions of social norms, such that students cannot readily "answer" or solve the puzzle of how, for example, to balance the tradeoffs associated with protecting water and biodiversity while producing food, without entering into a genuine STEM activity. These qualities met Penuel and Bell's (2016) definition of a "well-anchored phenomenon."

For example, from our experiences teaching with PEWI, and from hearing stories of others who have taught with PEWI, students often gravitate toward a feeling of "ownership" of the PEWI River, toward which all soil and water elements move in the watershed (i.e., by definition). Many students become attached and protective. Affective development is part of the Phenomenon element. It is from the river that contaminant levels are tested. Many students spend time puzzling how to reduce contaminants by selecting, sizing, and siting land use types. There are a tremendous number of combinations of approaches, so there are no immediate "right answers," another element of a well-anchored phenomenon.

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Some students "paint" the entire watershed with prairie, thinking that native perennials are the best way to protect the water. They learn through the results that this "eco" solution likely would have benefited from examining drainage and topographic maps beforehand. Also, the results show that the solution removed most income opportunities from residents in the watershed. Because PEWI is a simulation, the practice is to develop another line of inquiry, and try again.

Other students warm to the land uses, and bring prior knowledge and affection to selections of, for example, cows on pasture or raising vegetables. Their choices may have intended impacts or may show the students that information in the underlying maps are more important than they anticipated. The varying social, emotional, and biophysical logics are fueled by choices inherent in PEWI and fit the Phenomenon term.

Phenomenon can be intensified by psychomotor, sensory, and social experiences if the PEWI simulation is paired with outdoor or local opportunities for testing water or visiting local rivers and streams, communities, producers, and sites of agricultural production.

Additionally, PEWI provides opportunities for students to work with *observable elements* (i.e., data measured by science) and a *defined case* (e.g., the realistic PEWI watershed, bifurcated by the PEWI River, with corresponding maps), which also anchor students to the unit (Penuel & Bell, 2016).

## 6.3 | Criterion B: Three-Dimensional Learning

The 3-D concept bundles (a) science and engineering practices, (b) disciplinary core ideas, and (c) cross-cutting concepts.

For illustration of PEWI's fit with the 3-D concept, we show selections from an PEWI Introductory Lesson Plan (Whitehair & Grudens-Schuck, 2019) that orients both students and teachers toward using PEWI's simulation powers but starting at a bottom rung of the scaffold (Figure 4).

### 6.3.1 | Science and engineering practices. Rated: Extensive (4/4)

PEWI's activities structure student actions as inquiry behaviors. Students plan virtual investigations, locate sources of data, measure, analyze, and interpret tabular and contemporary data visualizations. Additional rounds of inquiry are a foremost activity of PEWI, contributing strongly to the NGSS practice element of developing and using models. Many students, and teachers, need to follow directions to master the sequence of establishing a baseline measurement, providing an input, measuring an output (which might represent a change), and documenting. If students are adept at inquiry behaviors, they can make informed choices. These eventually become practices that more similar to inquiry or testing behaviors.

**EXAMPLE LESSON PLAN**

**Introductory Lesson 1: Changing Nitrate Levels in the PEWI River**

***Overall Learning Goal***

Students will connect changes in the levels of nitrate (in the form of nitrate ppm) in the PEWI River to the types of land uses applied on the PEWI watershed.

*Learning Objectives:* By the end of this lesson, learners will be able to:

1. Access the PEWI simulation and be able to use basic game options.
2. Locate data on the Results table and record two nitrate measures under two different land use conditions.
3. Change land use applications on the watershed using the land use menu.
4. Access the Glossary for definitions of land uses and other terms.
5. Report results in a simplified table (see template at end of lesson plan) (not provided).
6. Track visually how nitrate flows downhill on the watershed from the land use to the PEWI River.

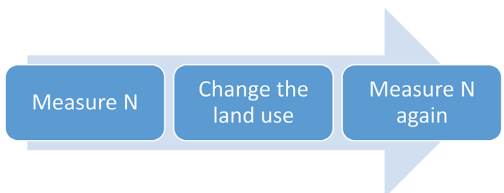
Next, we will change the level of nitrate in the PEWI River. We meet this goal by changing the land use type.

Content note for teacher. More in Glossary. Nitrate is present in river and other surface water at all times. At different levels, it is considered to be a pollutant or contaminant. On agricultural and rural watersheds, a big source of N is the land use.

A key strategy in PEWI: To change the level of nitrates (N) in the water, change the land use.

The simulation, or model, follows these steps:

- Measure the element or feature you are concerned about (information in glossary)
- Document (write it down somewhere)
- Apply a new land use or change the amount (acreage) of an old one
- Measure again
- Document
- Repeat




We will use this process to attempt to change the level of nitrate in the PEWI River.

Congratulations if you made the nitrate level move either way!

What could it mean if you ended with a higher N score in the Control category? Lower?

What could that mean about your land use if the in-stream nitrate concentration went up or down?

[Teacher: The scales run in different directions. The ppm is a measure of the chemical, and "more" means worse for water. The Control measure means that better care has been taken to lessen nitrates, so "more" means better control, so a lower score means improvement. This might be a good time to look at the Results graphics.]

**FIGURE 4** Selections from the Introductory Lesson Plan. The PEWI lesson plan 1: Nitrate (Whitehair and Grudens-Schuck, 2019)

### 6.3.2 | Disciplinary Core Ideas. Rated: Adequate (3/4)

Content from life sciences, earth science, physical and space sciences, and engineering and technology sciences in PEWI is provided through maps, and through data in Results tables, and in a Glossary. Life and earth sciences are the main disciplinary partnership. The emphasis is on use rather than development, memorization, depth, or retention of concepts.

PEWI was not designed as a text environment and was not intended as a replacement as a content-focused resource. However, while not lengthy, the 110 entries of resource material in the Glossary were research-based, and pertinent to the agroecosystem and watershed concepts. It was important for students and teachers to have access to definitions of, for example, "conventional corn" and "conservation corn" so they could comprehend choices beyond "cornfield." Students and teachers likely would not locate reliable information about corn production systems in a compact form on the internet if we did not provide it. Moreover, we strove for compact and purposefully limited video, text, and audio because the research on DGBL recommended this approach to design. The visual aspects of the game also support learning, such as the watershed and river shape and proportions, the maps, and the flyover feature. As part of a simulation DGBL, which fills a gap in STEM and agriculture, the score of "acceptable" (3/4) seemed to be an apt portrayal.

### 6.3.3 | Cross-cutting Ideas. Rated: Extensive

Cross-cutting concepts emphasized in PEWI include demonstration of scale, proportion, and quantity and play key roles in showing logic of cause and effect. Engineering, as well as science, concepts, are pertinent to addressing watershed and water quality mitigation strategies. The cells represent an acreage proportion, and coverage by a land use affects Results proportionally. Structure and function can be demonstrated in the PEWI model by scaffolding of use of maps and Results.

The introductory lesson plan was created to set a student on a path toward inquiry. As this lesson plan ends, it indicates to the teacher to provide a reward to students for making any gains in making the system PEWI science and engineering practices work. The teacher is not solely focused on the outcome of lowering the nitrate levels, even though this goal may be apparent given the starting conditions of the land use of conventional corn on the watershed. The key achievement for student learning outcomes is science and engineering practices: how to improve thinking. Therefore, any change, up or down, as long as the process is followed, is rewarded in this process. The introductory lesson plan ends with questions that urge reflection on results. A second introductory lesson plan adds complexity and builds on lesson plan one.

## 6.4 | NGSS performance expectations

We then used the NGSS Framework concept of Performance Expectations to characterize the fit of PEWI to the standards. Each performance expectation is composed of 3-D elements, listed in Appendix A of the *Framework*, and available in a separate document, *Topic Arrangements of the Next Generation Science Standards* (Achieve, Inc., 2017). Column 1 of Table 1 provides the title, code, and Performance Expectation for matches to PEWI. If there was no evidence of a match, we did not include the item. Evidence for the fit of PEWI to each of the codes, developed by the team, is provided in the second column.

## 6.5 | AFNR career content cluster standards

The AFNR Career Content Cluster Standards (National Council for Agricultural Education, 2015) matrix includes the career pathway, the standard and its description, the specific indicator and description, and a description of alignment for the indicators to PEWI content.

# 7 | DISCUSSION

The alignment process for the PEWI DGBL game provided evidence that key concepts associated with NGSS were met for the following levels:

1. Phenomenon (extensive)
2. 3-D learning cluster composed of: (a) science and engineering practices (SEP) (extensive), (b) disciplinary core ideas (DCI) (adequate), and (c) cross-cutting concepts (CCC) (extensive)

The area in which PEWI scored weaker was based on the game's limited provision of text/audio-based content for DCIs. The glossary that PEWI provides in the form of 110 videos and as-needed text clarifies concepts essential to the agroecosystem and science elements of the game, but each entry is intentionally brief, in keeping with good principles of game design. The content is not sufficient for students to master disciplinary core ideas. Moreover, because PEWI can fit curriculum goals of several content areas, it is not fully known what broader content it should address.

That said, altering PEWI to provide sufficient content, such as a textbook might provide, move the game closer in design to a "text environment," which our team would deem undesirable. For DGBL, a text environment is considered to be a passive construction, and simulations seek to engage students (Moreno et al., 2001), especially in learning complex systems (Yoon et al., 2018).

**TABLE 1** Student performance expectations, titles and codes, from Next Generation Science Standards (NGSS), and the People in Ecosystems Watershed Integration (PEWI) evidence for alignment (National Research Council, 2016). HS in first part of code indicates high school grade-band

| Student performance expectations NGSS title and code | Evidence from PEWI |
|---|---|
| Interdependent relationships in ecosystems<br>HS-LS2-2<br>Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. | PEWI calculates results for biodiversity within the watershed based on the type and proportion of land uses by 10-acre cell units. Students' choices create trends between years that affect the biodiversity measure, which is displayed numerically, in slide form, and in graphic visualization. |
| Interdependent relationships in ecosystems<br>HS-LS2-7<br>Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. | Students may select a single or paired impact that is concerning to them or to a community, such as nitrates or sediment in water, and test combinations of land uses that reduce the contaminant to a desired level (perhaps set by policy or law). |
| Interdependent relationships in ecosystems<br>HS-LS4-6<br>Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. | Students may select game wildlife or biodiversity ecosystem services to increase, and test proportions or types of land uses that mitigate scarcity while maintaining economic productivity of the watershed through retention of agricultural crops. |
| Engineering design<br>HS-ETS1-3<br>Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. | Advanced PEWI features, such as several map features, flyover features, and economics functions, may be combined with outside and/or local resources to design pragmatic or ideal watershed designs that fit a pressing context. |
| Engineering design<br>HS-ETS1-4<br>Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. | Using solely PEWI data, ideas from students can be used to compare tradeoffs of future situations that affect local or remote situations related to any of the ecosystem measures. |
| Human sustainability<br>HS-ESS3-3<br>Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations, and biodiversity. | Students can track the relationship and levels of conservation, proportion of agriculturally productive land uses, uses of land to reduce of contamination, and support biodiversity, to create the best management practices for the watershed. |
| Human sustainability<br>HS-ESS3-4<br>Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. | Students focus on a key land use or pair of land uses, and test general knowledge gained through outside resources, for crop production, livestock production, and/or conservation practices, design their own solutions to reduce human impacts on natural resources. Students discuss what can be learned from general resources compared to a digital simulation. |
| Human sustainability<br>HS-ESS3-6<br>Use a computational representation to illustrate the relationships among Earth system and how those relationships are being modified due to human activity. | Students explore how human decisions of land usage practices have a long-term impact on factors including soil erosion, nitrate pollution, phosphorus pollution, and carbon sequestration. Students explore how underlying conditions such as landforms (drainage maps, typography) compound human decisions such as land use selection. |
| Human sustainability<br>HS-ESS3-1<br>Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. | Students communicate, using the language of science and engineering, how they used the model to measure, test, and re-measure to hone a problem such that a solution was more manageable. Students practice the language of measures and units, land uses, and causality important to climate conversations. |

**TABLE 2** Evidence of the People in Ecosystems Watershed Integration (PEWI) alignment to Agriculture, Food, and Natural Resources (AFNR) Standards (National Council for Agricultural Education, 2015)

| Standard/indicator | AFNR description | Evidence from PEWI |
|---|---|---|
| Cluster skills CS.02 | Evaluate the nature and scope of the Agriculture, Food and Natural Resource Career Cluster and the role of agriculture, food, and natural resources in society and the economy. | |
| Indicator CS.02.01 | Research and use geographic and economic data to solve problems in AFNR systems. | Data in results table shows students how impacts of land uses depend on topography, flood frequency, sub-watershed boundaries, drainage class, soil class, and yield capabilities. |
| Indicator CS.02.02 | Examine the components of the AFNR systems and assess their impact on the local, state, national, and global society and economy. | Results table shows students how changes in data, based on student selections related to land uses, depend on soil, water, nutrient cycles, plant productions, and economics. |
| Cluster skills CS.04 | Demonstrate stewardship of natural resources in AFNR activities. | |
| Indicator CS.04.01 | Identify and implement practices to steward natural resources in different AFNR systems. | Glossary descriptions of land uses lead students to examine simulated impacts on ecosystem services, including water quality, game wildlife, and biodiversity. |
| Cluster skills CS.06 | Analyze the interaction among AFNR systems in the production, processing, and management of food, fiber, and fuel and the sustainable use of natural resources. | |
| Indicator CS.06.01 | Examine and explain foundational cycles and systems of AFNR. | Glossary provides students access to information regarding nutrient cycling (nitrogen, phosphorus), and results table shows effects of production of food, fiber, and fuel, including livestock. |
| Environmental service systems ESS.03 | Develop proposed solutions to environmental issues, problems, and applications using scientific principles of meteorology, soil science, hydrology, microbiology, chemistry, and ecology. | |
| Indicator ESS.03.02 | Apply soil science and hydrology principles to environmental service systems. | Students make land use decisions based on maps of drainage class, soil class, strategic wetland placements, and flood frequency to maximize the production potential while minimizing the negative impacts. |
| Indicator ESS.03.05 | Apply ecology principles to environmental service systems. | The results function calculates scores for game wildlife and biodiversity, showing students the impacts that land use decisions have on environmental systems. |
| Environmental Service Systems ESS.05 | Use tools, equipment, machinery and technology common to tasks in environmental service systems. | |
| Indicator ESS.05.01 | Use technological and mathematical tools to map land, facilities and infrastructure for environmental service systems. | Students evaluate specific data for an area of land through calculations of the watershed and through PEWI maps. |
| Natural resource systems NRS.01 | Plan and conduct natural resource management activities that apply logical, reasoned, and scientifically based solutions to natural resource issues and goals. | |
| Indicator NRS.01.02 | Classify different types of natural resources to enable protection, conservation, enhancement, and management in a particular geographical region. | Students use the glossary and maps to make decisions that impact watersheds differentially for game wildlife, biodiversity, and to guide efforts for enhanced conservation. |

(Continues)

**TABLE 2** (Continued)

| Standard/indicator | AFNR description | Evidence from PEWI |
|---|---|---|
| Indicator NRS.01.03 | Apply ecological concepts and principles to atmospheric natural resource systems. | Glossary provides students with terminology for nitrogen and carbon cycles, including carbon sequestration. |
| Indicator NRS.01.04 | Apply ecological concepts and principles to aquatic natural resource systems. | Students examine science-based flow of water using maps, land uses in a watershed, and water quality indicators. |
| Natural resource systems NRS.02 | Analyze the interrelationships between natural resources and humans. | |
| Indicator NRS.02.02 | Assess the impact of human activities on the availability of natural resources. | Students visualize the impact that human production and land choices have on natural resources, and test ideas through rapid, science-based simulation. |
| Indicator NRS.02.04 | Examine and explain how economics affects the use of natural resources. | Decisions that students make are made based on tradeoffs between economical production practices and the enhancement of natural resources. |
| Natural resource systems NRS.03 | Develop plans to ensure sustainable production and processing of natural resources. | |
| Indicator NRS.03.02 | Demonstrate cartographic skills, tools, and technologies to aid in developing, implementing, and evaluating natural resource plans. | Student view topography, including use of flyover feature, gross erosion, and phosphorus risk assessment maps to create land use designs that can be printed and displayed for group discussion. |
| Natural resource systems NRS.04 | Demonstrate responsible management procedures and techniques to protect, maintain, enhance, and improve natural resources. | |
| Indicator NRS.04.01 | Demonstrate natural resource protection, maintenance, enhancement, and improvement techniques. | Students understanding of how land use decisions impact water quality, habitats for wildlife, and biodiversity and construct landscape designs. |
| Plant systems PS.04 | Apply principles of design in plant systems to enhance an environment (e.g., floral, forest, landscape, and farm). | |
| Indicator PS.04.01 | Evaluating, identifying and preparing plants to enhance an environment. | Students use the glossary to identify, select, and use plants in land use decisions; and are guided in placement by maps on topography, drainage class, and wetlands. |
| Indicator PS.04.02 | Create designs using plants. | Students use the glossary to identify, select, and use plants in land use decisions; and are provided data on impacts. |

Finally, with regard to NGSS, we provided evidence for matches to nine NGSS performance expectations in three areas for the high school grade-band. There is potential for further evaluation of PEWI for alignment to NGSS for areas such as assessment, instruction, coordination among grade levels, and across content areas. We selected elements of the standards for alignment but stopped short of a comprehensive evaluation. More detailed study would deliver reliable results if conducted on a classroom or institutional basis rather than this current broader review context. We were also aware that the NGSS process, through Achieve, Inc., was accepting submissions of curricula for review, and will be considering this additional resource for betterment.

The PEWI evaluation for alignment to AFNR provided evidence for fit to 10 standards and 17 indicators in the areas of Environmental Service Systems, Natural Resource Systems, and Plant Systems (Table 2). Several of the glossary areas specific to production agriculture use contemporary terms and maps that are used professionally by agricultural advisors employed by farmers and landowners, enhancing the career readiness of graduates.

## 8 | CONCLUSION

Alignment of a watershed and land use game, PEWI, to NGSS and AFNR standards resulted in similar representations of the game as a potentially rewarding curricular contribution to STEM and agriculture education. Areas of alignment included matches to performance expectations and learning objectives served less well by traditional curricula, such as science and engineering practices that engage students in a simulation environment, and in science and engineering practices. PEWI provides high-quality experiences in content areas that many students and teachers already care about: land, food, and water, and our collective impetus to improve the earth and the human condition.

However, PEWI is not strong in all areas. The simulation does not provide sufficient resources, by itself, to build content area mastery in the subject areas of soil, water, and crops, and should not supplant other curricula, and excellence in the teaching profession, that already provide this function. Nevertheless, PEWI offers to fill the gap in science and agriculture education related to teaching underserved concepts of inputs and outputs and understanding complex systems that are necessary to global challenges of sustainability.

## ACKNOWLEDGMENTS

We appreciate funding and support from Iowa State University Departments of Natural Resource Ecology and Management; Agricultural Education and Studies; and Agronomy. USDA McIntire-Stennis Program (IOW5423, IOW5534), USDA NIFA Award 2018 67019-27886, and Iowa State University Extension and Outreach supported development of the standards alignment, and the Teachers Guide. The article is improved due to the efforts of two anonymous reviewers.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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## REFERENCES

Achieve, Inc. (2017). Topic arrangements of the Next Generation Science Standards. Retrieved from https://www.nextgenscience.org/sites/default/files/AllTopic.pdf

All, A., Castellar, E. P. N., & Van Looy, J. (2016). Assessing the effectiveness of digital game-based learning: Best practices. *Computers & Education*, 92–93, 90–103. https://doi.org/10.1016/j.compedu.2015.10.007

An, Y-J., Haynes, L., D'Alba, A., & Chumney, F. (2016). Using educational computer games in the classroom: Science teachers' experiences, attitudes, perceptions, concerns, and support needs. *Contemporary Issues in Technology and Teacher Education*, *16*(4), 415–433.

Annetta, L. A. (2008). Video games in education: Why they should be used and how they are being used. *Theory Practice*, *47*(3), 229–239. Retrieved from https://www.jstor.org/stable/40071547

Bellotti, F., Kapralos, B., Lee, K., Moreno-Ger, P., & Berta, R. (2013). Assessment in and of serious games: An overview. *Advances in Human–Computer Interaction, 2013,* 13864. https://doi.org/10.1155/2013/136864

Bourgonjon, J., De Grove, F., De Smet, D., Van Looy, J., Soetaert, R., & Valcke, M. (2013). Acceptance of game-based learning by secondary school teachers. *Computers & Education*, *67*, 21–35. https://doi.org/10.1016/j.compedu.2013.02.010

California Academy of Sciences. (2020). About Cornucopia. Retrieved from https://www.calacademy.org/educators/about-cornucopia

Chennault, C. M., Schulte, L. A., & Tyndall, J. C. 2016. People in Ecosystems/watershed integration: A web-based learning tool for evaluating ecosystem service tradeoffs from watersheds. *Journal of Soil and Water Conservation*, *71*, 31A–36A. https://doi.org/10.2489/jswc.71.2.31A

Congressional Research Service. (2019). Tribal broadband: Status of deployment and federal funding programs, No. R44416. Retrieved from https://crsreports.congress.gov

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*, 661–686. https://doi.org/10.1016/j.compedu.2012.03.004

Fulmer, G. W., Tanas, J., & Weiss, K. A. (2018). The challenges of alignment for the Next Generation Science Standards. *Journal of Research in Science Teaching*, *55*, 1076–1100. https://doi.org/10.1002/tea.21481

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow, and immersion in game-based learning. *Computers in Human Behavior*, *54*, 170–179. https://doi.org/10.1016/j.chb.2015.07.045

Iowa Department of Education. (2018). Condition of education: 2017 annual report. Des Moines: Iowa Department of Education. Retrieved from https://files.eric.ed.gov/fulltext/ED583725.pdf

Law, V., & Chen, C. (2016). Prompting science learning in game-based learning with question prompts and feedback. *Computers & Education*, *103*, 134–143. https://doi.org/10.1016/j.compedu.2016.10.005

Moreno, R., Mayer, R. E., Hiller, A., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction*, *19*(2), 177–213. https://doi.org/10.1207/S1532690XCI1902_02

National Council for Agricultural Education (NCAE). (2015). National Agriculture, Food and Natural Resources (AFNR) career cluster content standards. Indianapolis, IN: NCAE. Retrieved from https://thecouncil.ffa.org/afnr/

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: NAP. https://doi.org/10.17226/13165.

National Research Council (NRC). (2013). *Next generation science standards: For states, by states*. Washington, DC: NAP. https://doi.org/10.17226/18290

Natural Resource Ecology and Management. (2019). *People in Ecosystems Watershed Integration (PEWI) v3*. Ames: Iowa State University. https://doi.org/10.31274/nrem-20191121-1

Natural Resource Ecology and Management. (2020). People in Ecosystems Watershed Integration (PEWI). Retrieved from https://www.nrem.iastate.edu/pewi/

NGSS Lead States. (2016). EQuIP rubric for lessons and units: Science. Ver. 3.0. Retrieved from https://www.nextgenscience.org/sites/default/files/EQuIPRubricforSciencev3.pdf

Nutrien. (2020). Journey 2050. Retrieved from http://www.journey2050.com/

Penuel, W. R., & Bell, P. (2016). *Qualities of a good anchor phenomenon for a coherent sequence of science lessons*. Seattle: University of Washington Institute for Science + Math Education. Retrieved from http://stemteachingtools.org/brief/28

Prior, J. C. (1991). *Landforms of Iowa*. Iowa City: University of Iowa Press.

Rodela, R., Ligtenberg, A., & Bosma, R. (2019). Conceptualizing serious games as a learning-based intervention in the context of natural resources and environmental governance. *Water*, *11*(2), 245. https://doi.org/10.3390/w11020245

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, *58*(1), 136–153. https://doi.org/10.1016/j.compedu.2011.07.017

Water Rocks. (2020). *Rock your watershed! A game of choice and chance*. Ames: Iowa State University. Retrieved from http://water-rocks.herokuapp.com/game/index

Whitehair, R. L., & Grudens-Schuck, N. (2019). *PEWI lesson plan 1: Nitrate*. Ames: Iowa State University.

Wisconsin Energy Institute. (2015). *Smartscape decision support system*. Madison: University of Wisconsin. Retrieved from https://dss.wei.wisc.edu/.

WGBH Educational Foundation. (2020). NOVA evolution lab game. Retrieved from https://iowa.pbslearningmedia.org/resource/nvev-sci-evolab/nova-evolution-lab-game/

Yoon, S. A., Goh, S., & Park, M. (2018). Teaching and learning about complex systems in K–12 science education: A review of empirical studies, 1995–2015. *Review of Educational Research*, *88*(2), 285–325. Retrieved from https://doi-org.proxy.lib.iastate.edu/10.3102/0034654317746090

**How to cite this article:** Anderson K, Grudens-Schuck N, Valek R, Schulte LA, Smalley SW. Alignment of a digital watershed and land use game to national education standards. *Nat Sci Educ*. 2020;49:e20005. https://doi.org/10.1002/nse2.20005