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Losing the Lake: Simulations to Promote Gains in Student Knowledge and Interest about Climate Change

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Climate change literacy plays a key role in promoting sound political decisions and promoting sustainable consumption patterns. Based on evidence suggesting that student understanding and interest in climate change is best accomplished through studying local effects, we developed a simulation/game exploring the impact of climate change on the declining water levels in Lake Mead. Because there are few evaluations of educational games using true control groups, this study also presents a randomized field trial evaluating the game. We randomly assigned 119 seventh graders to either a game-based condition or control condition. Students in the experimental group played Losing the Lake; those in the control group viewed an earth science website. Students also completed pretest, posttest, and delayed posttest measures of their content understanding and interest in issues embodied in the game. We found that playing the game resulted in a significant increase in content knowledge, as measured by a 22-item assessment, especially on items related to household conservation and some basic concepts related to the greenhouse effect. The control group showed no effect. Playing

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the game also resulted in some increase in student interest. The Losing the Lake game illustrates how use of a water theme can be used to make climate change content more meaningful and relevant to students. Furthermore, the study shows, through a randomized control trial, that educational games can result in conceptual development, specifically on water flow (i.e., where drinking water comes from and where it goes once used), water conservation, and the difference between weather and climate. The Losing the Lake game can therefore be useful educationally in various locales as a case study in the nature of drought, climate change effects, and water conservation practices.

Keywords: simulations, sustainability, climate change education, water resource management, educational game

INTRODUCTION

Anthropogenic climate change has caused a variety of adaptation and mitigation challenges for modern societies. These include increased frequency of drought, floods, storms, and other natural disasters, as well as consequences related to disease (Intergovernmental Panel on Climate Change [IPCC, 2007]). Climate change literacy plays a key role in promoting sound political decisions and promoting sustainable consumption patterns (Anderson, 2012). However, few K-12 teachers have received any formal training on climate change and cite a lack of knowledge, as well as the complexity of the topic, as barriers to providing quality climate change education (National Research Council, 2012; Wise, 2010). Understanding climate change requires systems thinking (Mirchi, Madani, Watkins, & Ahmad, 2012; Sterman et al., 2012), including an understanding of various natural systems (carbon cycle, water cycle, etc.) and social systems (economic, political, etc.). Systems thinking involves understanding interaction and feedback effects within these systems (Shepardson, Roychoudhury, Hirsch, Niyogi, & Top, 2014). Finally, helping students understand climate change requires addressing and overcoming various misconceptions, such as confusing weather with climate or climate change with ozone depletion (Papadimitriou, 2004). It also involves promoting critical thinking about climate-related issues.

It is therefore important for teachers and students to be provided with instructional resources that enhance student understanding of the topic, for example through computer-based educational environments (Songer, 2007). The use of multimedia materials can transform the way students learn through visual engagement and promoting active learning (Plass et al., 2012). Computer simulations and games, if properly designed, have also been shown to promote systems thinking and understanding (Blikstein & Wilensky, 2009). Another body of research has shown that effective climate change education needs to focus on content that is tangible, meaningful, and actionable (Anderson, 2012). One such content area is water resources. Water is life-sustaining and something that all humans need and can relate to. Climate change, by altering long-term precipitation patterns, will exacerbate droughts, flooding, and other water-related phenomena (Carrier, Kalra, & Ahmad, 2013; Forsee & Ahmad, 2011; Kalra & Ahmad, 2012).

Although the number of computer-based climate change serious games has increased over the last few years (Reckien & Eisenack, 2013), few of these games focus specifically on water, and many of the latter were designed for water managers and decision makers (Valkering, Van der Brugge, Offermans, Haasnoot, & Vreugdenhil, 2012), not K-12 students. We therefore sought to develop an educational game that we call *Losing the Lake*. The game explores the effect of climate change on water resources in the southwestern U.S., specifically on water levels in Lake Mead. Lake Mead is the largest human-created reservoir in the United States and a major source of drinking water for three Western states and Mexico. The lake is fed by the Colorado River (Sagarika, Kalra, & Ahmad, 2014), and the river is fed by water from the Rocky Mountain snowpack. An extended drought over the last 14 years, made worse by climate change, has reduced the snowpack in the Rocky Mountains and, in turn, Lake Mead water levels.. The steadily declining water levels in the lake has had consequences which are highly visible, as shown in Figure 1.

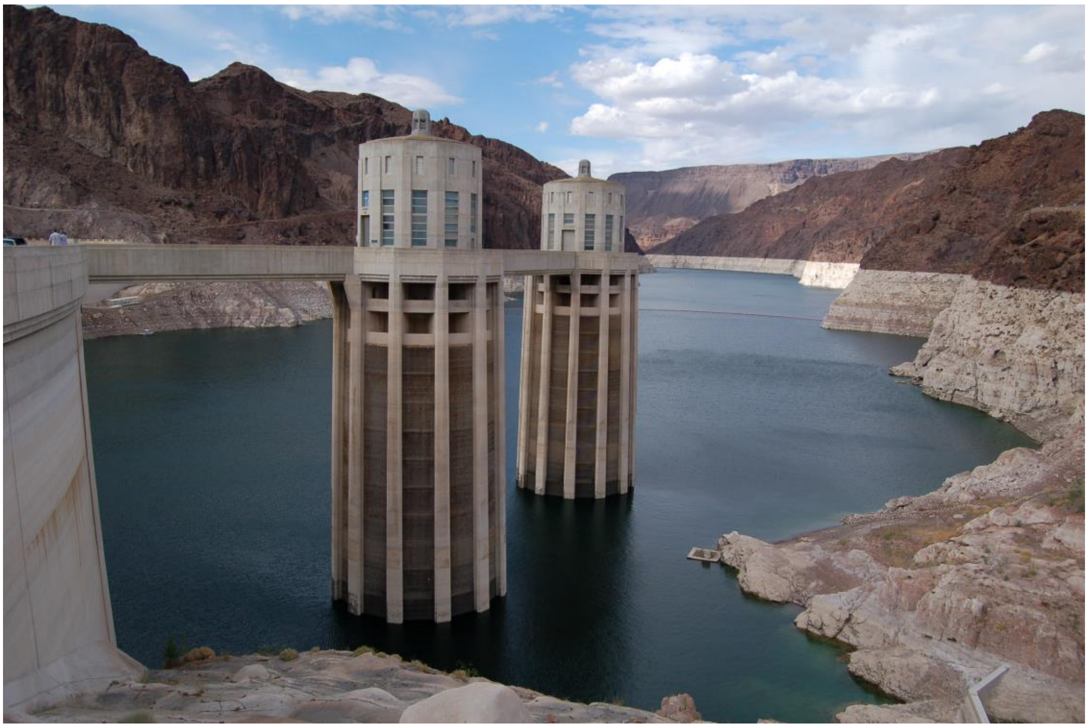


Figure 1. Lake Mead water level as of 2010. The white "bathtub" ring reflects exposed rock that was previously underwater. The ring shown here is approximately 130 feet (40 m) (©Photo by Lynn F. Fenstermaker, used with permission.)

Images such as these can be powerful symbols of the effects of climate change. Imagery is useful pedagogically for attracting student attention and illustrating local relevance (Messaris, 1997; O'Neill & Nicholson-Cole, 2009). We designed the game to further support student understanding of two complex systems/phenomena: the water supply system in Southern Nevada and the global greenhouse effect, as well as water conservation efforts. Although the design of the game has been described in some detail elsewhere (Nussbaum, Sinatra, Cordova, Owens, & Rehmat 2012; Nussbaum, Sinatra, & Owens, 2012; Vesco et al., 2012), this article briefly describes the game and—unlike previous reports—presents an experimental study of the game's effectiveness. The simulation models that provided some data for the activities on water conservation and lake levels are described in Dawadi and Ahmad (2012, 2013). We report on specific content areas where the game did (or did not) increase student knowledge, as well as effects on student interest and motivation.

Conceptual framework

The game (and study) address aspects of climate change literacy. Anderson (2012) presents several design principles of effective climate change education based on a systemic literature review conducted by the Brookings Institution, in conjunction with graduate students at Columbia University and New York University. The principles are as follows (from Anderson, 2012, pp. 198-199).

1. "Climate change literacy can be improved through *sustained, active learning activities using integrated, cross-discipline curricula.*"

2. "*Active learning should be connected to local problems solving….*Educational techniques that connect climate change with not only local issues but also individual behavior and impacts offer tremendous promise, both by making abstract concepts tangible and by linking the global phenomenon to individual action" (Duan & Fortner, 2005).
3. "While climate change education should inform students about the scientific concepts and implications of climate change, it is also important to *cultivate problem solving and critical thinking skills through framing messages to emphasize an individual's capacity to achieve positive outcomes*" (Morton, Rabinovich, Marshall, & Bretschneider, 2011; Spence & Pidgeon, 2010). Research has shown that appeals to fear and negative consequences can cause disengagement (O'Neil & Nicholson-Cole, 2009), whereas appeal to things that individuals can do to adapt to or mitigate negative consequences builds self-efficacy and stimulates deeper processing (Moser & Diller, 2007). Climate change education therefore needs to be action oriented (National Research Council, 2011).
4. "*Narrative techniques, visual imagery* (such as photographs) *and persuasive texts* are powerful tools" that make global climate change dynamics more understandable and engaging, and impact students' attitudes and behavioral intentions" (Niepold, Herring, & McConville, 2008; Sinatra, Kardash, Taasoobshirazi, & Lombardi, 2011).

In view of these design principles, we searched for a local problem related to climate change that was visually rich and that would invite students to problem solve. A local problem that met these criteria was the declining water levels in Lake Mead. The Nevada System of Higher Education had been awarded a $15 million grant from the National Science Foundation to research local problems related to climate change and strengthen infrastructure, outreach and education efforts. Through an interdisciplinary science award from the larger grant, our team of educators partnered with a civil and environmental engineer (Dr. Sajjad Ahmad) and two computer scientists at the University of Nevada, Reno (Dr. Fred C. Harris, Jr., & Dr. Sergiu M. Dascalu) to develop the *Losing the Lake* computer game. The game was intended as an instructional resource for middle school students as well as for the general public in informal environments (for example, the game was placed in the Las Vegas Natural History Museum). The game was a freestanding resource in the latter but in the middle school environment could be combined with other instructional activities. We developed a facilitator's manual containing suggestions for activities and discussions that could be combined with the game. Both the game and the manual are available on the web at:

http://sensor.nevada.edu/NCCP/Education/Losing%20the%20Lake/Default.aspx .

However, in this study, our goal was to evaluate the effects of just the game on student learning and motivation. Although we hypothesize that the effectiveness would be greater if combined with other instructional activities, testing this assumption is not our present goal. From a theoretical perspective, this study was meant to shed light not only on the effectiveness of *Losing the Lake* but also more broadly on the utility of using a water theme in connecting the meaningfulness of the issue of climate change to student learning and interest.

Game design

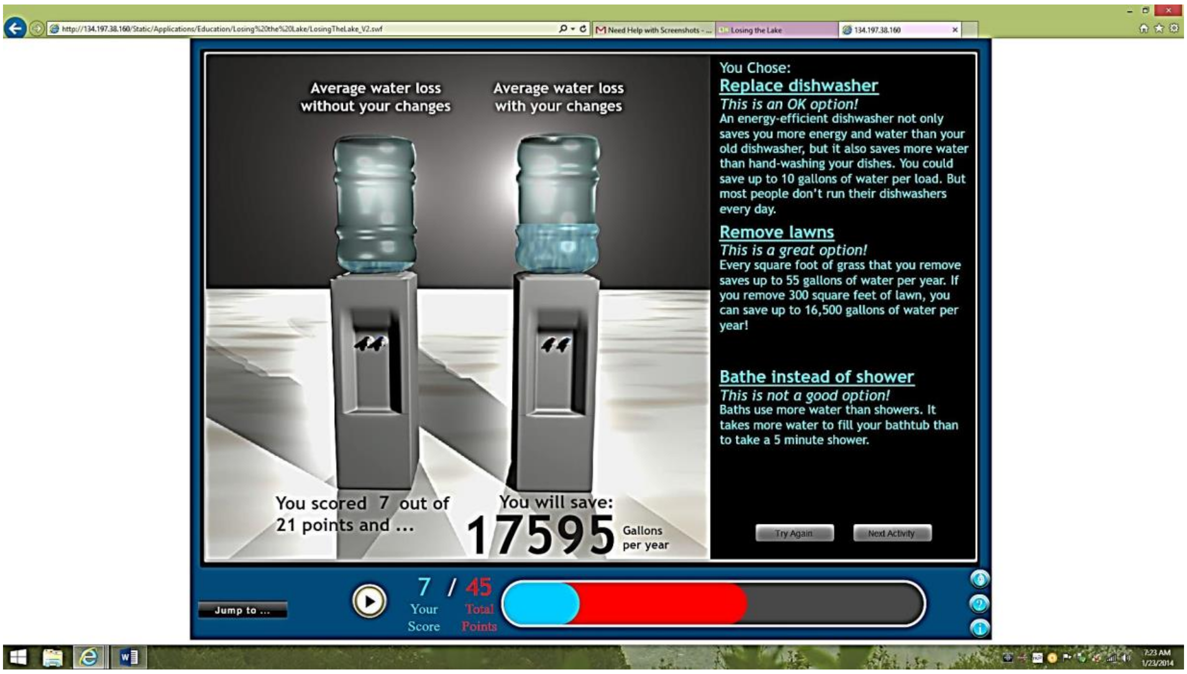
The 'Losing the Lake' game was designed with five modules/activities to help break down the complex topic of climate change. This specific design was employed with the idea that the game could be used as a whole or as modules for teaching the concepts of climate change and water conservation. Additionally, the modules/activities were created so the students could easily comprehend and digest climate change content and not be overwhelmed by the game as a whole. Table 1 describes the five modules/activities of the game.

Table 1. Description of game activities

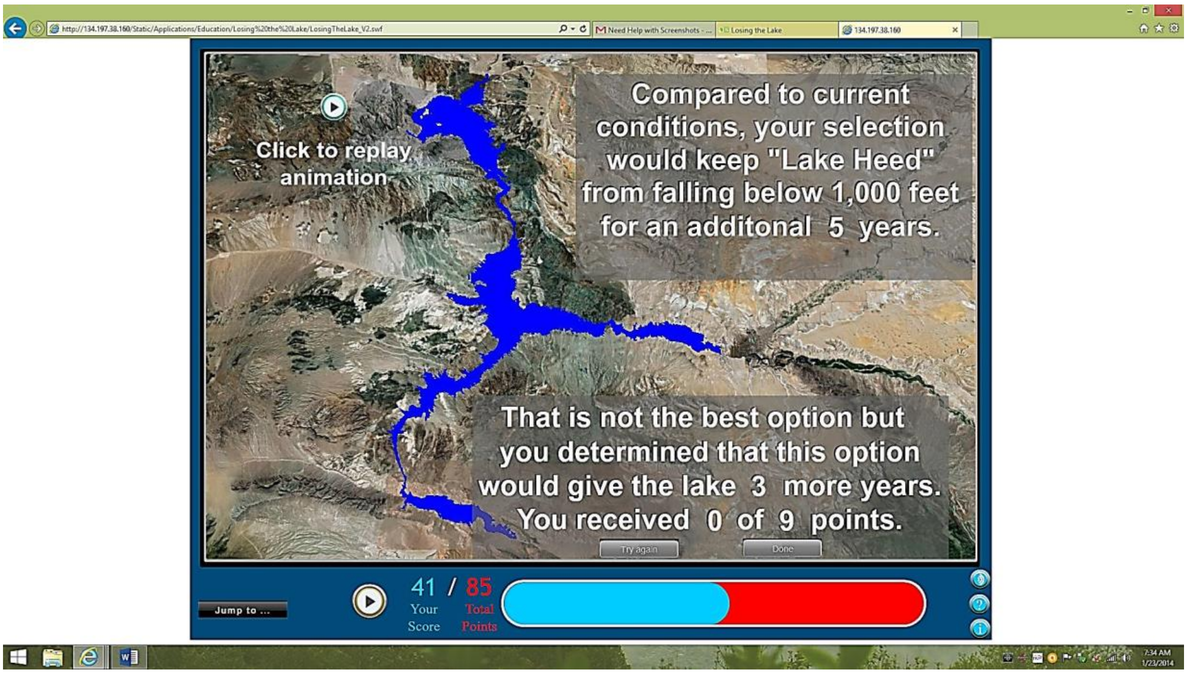
Activity	Purpose	Description
Multiple-choice questions (6)	Building background knowledge regarding snowfall, drought, climate change, greenhouse gases.	If users answer incorrectly, they can try answering again, and if still incorrect, are provided written feedback. Three alternative question sets were developed in the event that a user wants to replay the activity or game.
Household conservation	Building knowledge of conservation activities; enhancing self-efficacy.	Users select from a menu of options (e.g., fix leaky toilets, cover swimming pool, etc.) the three that will save a household the most water. There is a visual of the inside of a house and parts of it glow (e.g., toilet, swimming pool) when the related option is selected. Users earn points for their performance.
Community conservation	Building knowledge of conservation activities; enhancing self-efficacy.	Same as Activity 2 but options relate to things local or state policymakers could do to conserve water (e.g., raise water prices, promote desert landscaping). Some are poor options (e.g., turn off resort fountains). Activity performed against map of Las Vegas.
Climate change	Build a mental model regarding why lake levels are declining and connect it to climate change.	Consists of a series of vocal explanations, visuals, and small simulations regarding temperature, snowpack levels, greenhouse gas emissions, and lake levels.
Simulation of lake water levels	Apply previous concepts to a context like Lake Mead; illustrate how scientific models are used.	Users must predict how long it will be before lake levels decline to 1,000 feet (305 meter) above sea level. The simulation is then run on a visual model of the lake so that users can see the water declining. The computer simulations are based on hydrologic models using the Hadley Center 2-A1B global climate model data. Users earn points for how closely their prediction matches the model.

Table 2. Menus of potential conservation options in activities 2 and 3

Activity 2 (Household)	Activity 3 (Community)
• Fix leaking toilets & faucets	• Restrict resort water usage
• Replace dishwasher	• Turn off resort fountains
• Replace washing machine	• Reduce golf course watering
• Cover swimming pool	• Newer homes use grey water
• Remove lawns	• Water smart landscaping
• Do not wash car at home	• Pool regulation
• Plant trees	• Raise water prices
• Bathe instead of shower	• Control population growth
• Don't water lawn if windy or rainy	
• Install low flow faucets	
• Replace showerheads	
• Bathe or shower less often	



a) Example of feedback screen on household conservation options (Activity 2)



(b) Example of one simulation result from Activity 5.

Figure 2. Screenshots of *Losing the Lake*.

In designing the game, we were cognizant of design principle #3, regarding building students' self-efficacy for action and avoiding fear appeals. On the other hand, some level of alarm was needed to reflect the reality of climate change impacts and attract and hold student attention to the effects needed for mitigation. As a compromise, we designed the game (specifically Activity 2) to first highlight the problem (that a major source of drinking water is declining) but then the game quickly turns to the issue of water conservation in students' household (choose the three options from a menu that would save the most water) and then in Activity 3, in the community. (These options are shown in Table 2.) Students receive informative feedback and game points depending on the options selected (the amount of water saved is illustrated by water flowing into a water cooler, with sound effects. See Figure 2a). An early focus on conservation in *Losing the Lake,* specifically starting in Activities 2 and 3, is intended to alleviate anxiety and build self-efficacy.

Losing the Lake is also designed so that users focus on increasingly more complex environments and systems. The first activity is a series of six questions intended to build students' background knowledge (see Table 3). As noted above, the second activity focuses on household conservation, and the focus is expanded in the third activity to community conservation. The fourth activity is an extended tutorial (with mini-activities for which users earn points) that links the problem to climate change. The activity is cognitively complex because the user has to understand all of the following:

- Most of the drinking water in the Las Vegas Valley comes from Lake Mead.
- Precipitation in the form of snow creates the snowpack in the Rocky Mountains.
- Melting snow from the Rocky Mountain snowpack feeds the Colorado River, which in turn feeds Lake Mead. (The geography is shown to students.)
- Snow levels have been steadily declining, as have lake levels.

- Some of this decline is due to climate change (which refers to changes over a 30-year period or longer).
- Climate change is linked to the "enhanced" greenhouse effect, which will cause the planet to be hotter and rain and snow fall to decline in the region. (Users are asked to guess by what percent. The link between greenhouse gas emissions and global temperature is also reinforced with a brief graphical simulation involving a thermometer.)
- An increase in global temperatures will cause regional average temperatures to increase (users predict the extent).
- An increase in regional temperatures will reduce precipitation and reduce snow levels in the region. (Users simulate this relationship—based on actual forecasts—by moving a slider representing temperature that reduces a representation of snow levels.)
- The game ends with a slide explaining that "the increase in temperature that you just saw is an average for the whole year. It means there will probably be less snowfall in the winter, earlier spring warming, more water evaporation, and therefore less water in the Colorado River for us to use" (in the long-run).

Table 3. Examples of background knowledge questions

The most important factor in determining the amount of water flowing in the Colorado River is the amount of ________. • Rainfall in the area • Snowfall in the Rocky Mountains • Snowfall in the Sierra Nevada Mountains • Water flowing from other rivers into the Colorado
Greenhouse gas emissions contribute to global warming. In the United States, where do most of the greenhouse gas emissions come from? • Waste management processes • Volcanic gases • Agriculture • Burning of fossil fuels

Although the game would be less complex if students were not asked to make estimations, making such predictions followed by experimentation or simulation is a widespread practice in science education. It promotes active cognitive processing and conceptual change (through cognitive conflict) when there is a discrepancy between predicted and actual results (Kearney, Treagus, Yeo, & Zadnik, 2001).

Whereas the fourth activity shows how climate change will make the on-going drought worse in the decades ahead, the fifth activity returns to the issue of conservation, but from a regional perspective. Conservation in just the Las Vegas Valley will have little effect on Lake Mead water levels because Nevada uses only a small allocation from the lake (its allocation, less than 2%, is the smallest amount of the seven states with a water allocation); however, regional conservation can make a difference. Users are introduced to the concept of mathematical and hydrologic modeling, and then are asked to pretend that they are water resource managers for a fictional lake in the southwestern U.S. (known as "Lake Heed") which is like Lake Mead and has water levels that are dangerously low. They make predictions regarding which of four options (20% municipal water conservation, doubling municipal water prices, 20% agricultural water conservation in California, and reducing global greenhouse gas emissions) will save the most water and extend the number of years before lake levels fall below 1,000 feet (305 meters) above sea level. (When the level drops below 1,000 feet, no more water can be drawn from the lake for Las Vegas because of the location of the intake pipes.) User predictions are then compared against actual results from scientific modeling using the global climate model Hadley Center 2-A1B data (with points earned based on how closely user predictions match the simulated ones). The results of one simulation are shown in Figure 2b.

Because there are a number of other global climate models, and because existing conditions change (e.g., "current" water levels in Lake Mead), we did not want the simulation results from our game taken out of context, quoted by the media, or used inappropriately; the results are illustrative for pedagogical purposes only. This was the rationale for using a fictional lake in Activity 5.

At the end of the game, users are told that "we need to do a combination of all these options" and are then given their overall point total. High scores are reinforced with the adjectives "good" or "great." The last screen thanks the user for playing and directs them to go save some water. Users can also select some options for more information (links to other websites).

Playing the game takes approximately 20 minutes. The game has verbal narration, but the text of the narration is also shown on the screen in the event that audio is not available for some reason (e.g., noise levels are too high).

The current study evaluated the effectiveness of the game by examining whether there would be an impact on measures of both student knowledge and interest.

METHODS

Participants

To evaluate the effectiveness of the game, we recruited two 7th-grade earth science teachers to work with us on the evaluation; the teachers were from two different middle schools in a large, urban school district in the southwestern U.S. Both teachers taught seventh grade and allowed us to conduct the study in all their class sections (six sections for the teacher at School A and five sections for the other teacher at School B). When the study commenced, the teacher at School B had already completed a unit on weather and climate and the other teacher was just beginning a similar unit. The unit addressed the characteristics of the atmosphere and its effects on Earth's surface, energy transfer in the atmosphere and oceans, greenhouse gases, solar energy and the water cycle (Holt Science & Technology, 2006).

A total of 119 students participated in the study; of these, 21 students were Caucasian, 17 Asian, 66 Hispanic, 8 African American, and 7 other. 51% were males. Schoolwide, 19.9% were limited-English proficient at School A and 42.4% at School B.

Materials

Materials included a 22-item quiz developed by the research team to assess the content knowledge taught in the game. The items were primarily multiple-choice and true/false selected response (see appendix for the specific items), but two constructed-response items were also included, one pertaining to the importance of water conservation in the Las Vegas Valley and the other to water conservation options. For the first item ("Why is it important for the Las Vegas Valley specifically to conserve water?"), responses were scored on a 0-3 scale blind to condition. Responses received a score of 1 for mentioning a connection to Lake Mead, a score of 2 for mentioning lake water levels, and a score of 3 for mentioning drought or living in a desert. Fifty percent of the responses were scored by a second rater, and the inter-rater reliability was 86%. For the second item ("Describe three good ways of saving water in your home or apartment,") respondents received the same number of points for mentioning a specific conservation option as were awarded in the game. Table 4 shows the specific point values for the different options. (See Nussbaum, Sinatra, Cordova et al., 2012, for the rationales for the point values shown in the table.)

Table 4. Point values for different household conservation options

Option	Points
Fix leaky toilets and faucets	2
Replace dishwasher	0
Replace washing machine	4
Cover pool	7
Remove lawns	7
Do not wash car at home	1
Plants trees	0
Bathe instead of shower	0
Install low flow faucets	6
Replace showerheads	5
Bathe or shower less often	0
Don't water when windy or rainy	7

We also developed a 10-item interest survey to assess students' interest in learning about water conservation and climate change and a student feedback survey about the *Losing the Lake* game (see Tables 5 and 6). The items used 4-point Likert scales ranging from 1 ("no interest") to 4 ("high interest"). As described below, the survey was administered both before and after the intervention. The internal consistency of the interest survey was .81 before and .86 after the intervention. The feedback survey (which was administered just to the experimental group after viewing the game) consisted of seven 6-point Likert-scale items ranging from 1 (Strongly Disagree) to 6 (Strongly Agree). The internal consistency of these items was .89. The feedback survey also contained four open-ended items regarding what students learned, liked, and disliked about the game, and regarding what they would like to learn more about after playing *Losing the Lake.*

Finally, we prepared written sheets with a weblink to the game (for the experimental groups) and to a general earth science website (for the control group). The control group link was: <www.eduweb.com/portfolio/earthsystems>. The site contained short sections on different Earth Systems but contained no information on climate change. The specific topics covered included the Earth's crust and atmosphere, food webs, hydrology, and glaciers. The researchers monitored students when viewing the website and made sure that students remained on task.

Table 5. Student interest survey items

1. Knowing more about where the Las Vegas Valley gets its water.
2. Learning more about water conservation in the home.
3. Knowing more about water conservation in the community.
4. Learning more about the Colorado River system.
5. Learning more about climate change and global warming.
6. Understanding better how human activity impacts climate change.
7. Knowing more about how climate change affects water availability.
8. Understanding better how humans impact water availability.
9. Knowing more about scientific modeling.
10. Understanding how scientific modeling is used in making predictions and guiding decision making.

Notes. Items rated on a 4-point Likert scale (1 = no interest, 2 = low interest, 3 = medium interest, & 4 = high interest). Instructions to students were: "Please rate your degree of interest in the following activities by circling a number from 1 (No interest) to 4 (High Interest). Your answers will be kept strictly confidential and will not be identified by name."

Table 6. Student feedback survey items

1. I enjoyed playing *Losing the Lake*.
2. I was bored playing *Losing the Lake*.
3. I want to play *Losing the Lake* again.
4. Playing *Losing the Lake* seemed to drag on forever.
5. *Losing the Lake* was interesting to me.
6. I liked playing *Losing the Lake*.
7. I think playing *Losing the Lake* is a waste of time.
8. Please list at least two things you liked about *Losing the Lake*.
9. Please list at least two things you didn't like about *Losing the Lake*.
10. Please list at least two things you want to learn more about after playing *Losing the Lake.*

Notes. Items 1 – 7 rated on a 6-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = somewhat agree, 5 = agree, 6 = strongly agree).

Design and procedures

We used a pretest/posttest (and delayed posttest) randomized two-group experimental design, using the following procedures. First, parental consent and student assent forms were collected during the first few weeks of the semester. The actual study was split into four sessions. During the first session (25 min in duration), participating students completed a short demographics form, the pretest, and an interest survey. During the second session, which took place a day or two later, students were randomly divided—within each class—into experimental and control groups. (Assignments were made the day before using a random number generator in Excel.) Students in the experimental group went to the school's computer lab and played "Losing the Lake" for 25 min while the other students worked on unrelated schoolwork (e.g., reading their textbooks). Then students switched, with the control group going to the computer lab, where they explored the earth science website while the experimental group participants completed unrelated schoolwork. Session three occurred the following day and lasted 25 min; all participants completed the posttest, the interest survey and student feedback survey. Lastly, during the fourth and final session, which occurred a week or two later, all participants were given 25 min to complete the delayed posttest.

Scoring

For each applicable testing session, participants received scores for: (a) the objective items on the quiz, (b) each of the two constructed response items, (c) the interest survey, and (d) the student feedback survey (Likert items). One item (multiple choice #8) was removed from the objective test analysis because of poor discrimination (.03 posttest/delayed posttest) and ambiguity. The student feedback survey constructed responses were coded for emerging themes using nonhierarchical coding (Johnson & Christensen, 2004), with frequency counts tabulated for different categories.

Data analysis

Table 7. Means (& SDs, n) of outcome measures

Measure	Condition	
	Experimental	**Control**
Objective test (pre)	7.12 (1.97, 59)	6.95 (1.70, 61)
Object test (post)	8.36 (2.47, 59)	6.83 (1.77, 60)
Objective test (delayed post)	8.20 (2.80, 54)	6.86 (1.89, 58)
Open-ended item 1 (pre)	0.78 (1.22, 63)	1.31 (1.36, 62)
Open-ended item 1 (post)	0.97 (1.31, 63)	1.35 (1.34, 62)
Open-ended item 1 (delayed post)	0.95 (1.35, 63)	1.17 (1.42, 62)
Open-ended item 2 (pre)	1.13 (2.68, 60)	1.41 (3.26, 61)
Open-ended item 2 (post)	5.35 (6.29, 60)	2.62 (4.47, 60)
Open-ended item 2 (delayed post)	6.63 (6.65, 51)	4.05 (5.08, 58)
Interest (pre)	22.21 (4.32, 61)	23.01 (4.26, 60)
Interest (post)	23.10 (4.70, 59)	22.96 (5.29, 60)

For the statistical analyses, we used robust standard-error estimators and the generalized linear model (GLM) function in SPSS version 19 to conduct the analysis. (Because of repeated measures over time, Generalized Estimating Equations were used, with an autoregressive-1 error structure.) The specific GLMs fitted were: (a) for the objective test, normal errors and a quadratic functional form (given that we did not expect a linear trend over time), (b) for the first open-ended item, a cumulative logistic model (given the ordinal nature of the scoring), and (c) for the second open-ended item, a gamma error structure with the log-link (given that the data were heavily skewed toward zero). (All scores were increased by 1 point to prevent scores of zero, which do not have logarithms.) For the analysis of the interest items, a standard repeated measures ANOVA was conducted as no assumptions of the general linear model were violated.

For each test, we performed five planned comparisons. We hypothesized that the experimental group would show an increase from pretest to posttest and from pretest to delayed posttest, and that the means for the experimental group would be higher than for the control group at posttest and delayed posttest but not at pretest. The Bonferroni-adjusted $\alpha = .01$. The means and *SD*s for each outcome measure are shown in Table 7.

RESULTS

Objective test scores

As we had hypothesized, the objective test scores significantly increased in the experimental group from pretest to posttest/delayed posttest but there was no gain in the control group. The omnibus test was significant (Wald $\chi^2 = 9.83$, $p = .002$) for the interaction between group and time (see Table 8 for the complete test of model effects).

Table 8. Objective test model effects

Term	B	95% CI	Wald χ^2	*p*-value
(Intercept)	4.43	[2.55, 6.30]	105.95***	<.000
Group (G)	-3.33	[1.01, 5.65]	7.91**	.005
Time (T)	3.37	[1.24, 5.50]	3.41	.065
T^2	-0.71	[-1.22, -0.19]	2.43	.119
G x T	4.24	[-6.89, -1.59]	9.83**	.002
G x T^2	-0.89	[0.23, 1.54]	7.06**	.008

Notes. Model fit: QICC = 1.478.214; Scale estimate 4.33.
**p* < .05. ***p* < .01. ****p* < .001.

Table 9. Objective test expected marginal means by time and group

	Expected Means		
Time	**Experimental**	**Control**	**(Total)**
Pretest	7.09	7.07	7.08
Posttest	8.35	6.75	7.55
Delayed Post	8.19	6.79	7.49
(Total)	(7.88)	(6.87)	(7.37)
	Wald 95% Confidence Interval		
Time	**Experimental**	**Control**	**Total**
Pretest	[6.60, 7.58]	[6.68, 7.46]	[6.77, 7.39]
Posttest	[7.72, 8.97]	[6.34, 7.15]	[7.18, 7.92]
Delayed Posttest	[7.47, 8.91]	[6.31, 7.28]	[7.06, 7.93]
Total	[7.38, 8.38]	[6.56, 7.18]	[7.08, 7.67]

The expected marginal means are shown in Table 9. The scores for the control group remained flat, but those for the experimental group increased from pretest to posttest. The increase from pretest to posttest was significant ($p < .001$, $d = 0.63$) as was the increase from pretest to delayed posttest ($p = .001$, $d = 0.56$). In addition, the experimental group held their gain showing only a nonsignificant decline at the delayed posttest ($p = .87$). There was no significant difference between the groups at pretest ($p = .95$), but there was at posttest ($p < .001$, $d = 1.01$) and delayed posttest ($p =.002$, $d = 0.75$).

Table 10. Mean gain scores by item (for experimental group), from pretest to posttest

Item stem (*answer paraphrased*)	**Gain**	**%Correct (Post)**
What has the greatest effect on water levels in the Colorado River? (*snowpack*)	0.49***	69.5
Climate change and changes in weather are the same. (*false*)	0.19*	55.9
Humans cannot survive on Earth without the greenhouse effect. (*true*)	0.19**	69.5
There are ways to conserve water at home. Some ways save more water than others. Which of the following is the best way to conserve water? (*grey water*)	0.19*	27.1
What happens to the water that we are finished using in our homes? (*returned to lake*)	0.15*	32.2
There are ways to conserve water within your community. Some ways save more water than others. Which of the following is the best way to conserve water within your community? (*raise water prices*)	0.12	18.6
Which of the following contributes to an increase in greenhouse gases? (*car emissions*)	0.10	40.7
Which of the following is a greenhouse gas? (*CO_2*)	0.07	50.8
Over the past 100 years global temperatures have increased. (*true*)	0.07	91.5
Resorts and casinos waste a large amount of water. (*false*)	0.05	20.3
Which of the following options would save the most water? (*desert landscaping*)	0.02	16.9
Most of the water from Lake Mead is used for (*agriculture*)	0.02	8.5
If Lake Mead water levels decline below 1,000 feet above sea level, what will then happen? (*unable to pump water from lake*)	0.00	33.9
If climate change causes an increase in average temperature of the area, what happens to the water in Lake Mead? (*lowers*)	-0.02	57.6
Which of the following determines how much water Nevada can use from Lake Mead? (*compact*)	0.03	32.2
Having cities cut back 20% on their water use is estimated to delay Lake Mead water levels from declining below 1,000 feet (above sea levels) for how many years? (*5 years*)	-0.05	39.0
The greenhouse effect and the ozone hole are basically the same thing. (*false*)	-0.05	67.8
Human activities produce greenhouse gases. (*true*)	-0.05	69.5
Grey water systems recycle water that comes from: (*bathing*)	-0.07	16.9
Requiring everyone in the community to cover their swimming pool would save very little water. (*false*)	-0.14**	50.8

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 10 shows the specific items on which learning gains were the greatest. The largest (and statistically most significant) gains were on five items. Two of the items related to the determinants of water flow: Colorado River water volumes are affected by snowpack, and water, once used by the Las Vegas Valley is returned to Lake Mead. Two related to climate: Climate is different from weather, and the greenhouse effect is needed for human survival. The final item related to household options for saving water. The control group also showed a gain on this item (p =.006), but the gain (0.13) was only half that of the experimental group. All the gains in the experimental group were maintained at the delayed posttest except for the item relating to needing the greenhouse effect for survival. The mean for the item relating to car emissions was also significantly greater than at pretest (0.25 gain, p = .004). Finally, there was a significant decline on the swimming pool item (decline from pretest, -0.20, p =.01).

Performance on two conservation items was suboptimal. One question asked students to select which, of four options, would save the most water. The modal response concerned replacing old washing machines (50.8% chosen at posttest), whereas the correct answer was replacing lawns with desert landscaping. Likewise, on a community conservation item, the modal response was requiring everyone in the community to cover their swimming pools (19.6%), whereas the correct response was raising water prices. Nevertheless, pool covers was still rated in the game as an excellent option. For both these items, we suspect that because users selected and received feedback on different options, their learning about the different options was uneven. Our analysis of the constructed response items (presented below) suggests that students did learn from the game about important conservation options.

Disappointingly, there was no gain on the item that asked, "If climate change causes an increase in average temperature of the area, what happens to the water in Lake Mead?" Although 57.6% of the experimental group answered the question correctly at posttest, a sizable minority (43%) chose the alternative "The water in Lake Mead will rise due to the melting of the snowpack and therefore, more water flowing into the Lake." In fact, this is only true in the short-term; earlier spring melting will increase the amount of water evaporation and, over the long-run, this coupled with decreased snowfall will reduce lake levels once much of the permanent snowpack is gone.

In conclusion, the game did result in learning gains on the broad concepts addressed by the game. However, there were three popular misconceptions that were not effectively addressed, relating to casinos and resorts wasting a lot of water (untrue), the necessity of the greenhouse effect for human survival (effect significant at posttest but not maintained at delayed posttest), and that melting snowpack will cause lake levels to rise. Supplementary instruction is needed to reinforce these aspects of the game.

Constructed response scores

For the first constructed response question ("Why is it important for the Las Vegas Valley specifically to conserve water?"), there were no significant effects (e.g., for the interaction, Wald χ^2 = 0.70, p = .40). The overall mean score was 1.17 on a 0 to 3 scale.

The second constructed response question was, "Describe three good ways to conserve water in your home or apartment." There was a significant effect of time (Wald χ^2 = 22.15, p < .001, showing a linear but not quadratic trend) and significant Group by Time interaction (Wald χ^2 = 5.40, p = .02), favoring the experimental group.

Most of the planned comparisons were as hypothesized. For the experimental group, scores significantly increased from pretest to posttest (p < .001, d = 1.57) and from pretest to delayed posttest (p < .001, d = 2.05), and were significantly different from the control group at posttest (p = .006, d = 0.64) but not at pretest (p = .56).

The difference between the groups at the delayed posttest was not quite significant at the .01 level (p = .03, d = 0.56). This occurred because of a slight increase in scores in the control group. (This increase could have been due to the experimental group students talking about what they learned from the game with the control group during the delay.)

A content analysis of the responses in the experimental groups (posttest) showed that the most frequently mentioned option was covering swimming pools (22.7%), followed by "do not wash car at home" (13.3%), "remove lawns" (12%), and "newer homes use grey water" (10.7%). All these options were rated as great ones in the game, except for not washing cars at home, which was rated as just OK (because cars are typically washed only every few weeks). The one great option that was infrequently mentioned (2.7%) was "Don't water if windy or rainy"—therefore, additional supplementary instruction may be needed on this item.

Interest survey

Items 9 and 10 were deleted from the analysis because there were a very high number of missing values. (These items were on the back of the survey page and many students forgot to turn the survey over.) The analysis below is therefore based on the sum of Items 1-8 only. The interest survey was only administered at two time points (pretest and posttest).

The Group x Time effect was significant ($F(1, 110) = 3.98$, $p < .05$). In the experimental group, the means increased by one point (from 22.25 to 23.25, p = .015, d = .23) but did not change in the control group (23.01 at pretest, 22.9 at posttest, p = .69). The increase in interest was driven by the first two items on the survey (learning more about where the Las Vegas Valley gets its water, p = .002, and learning more about home water conservation, $p < .001$).

Student feedback survey

For the experimental group, the mean score on the Likert-scale items (with some items reversed scored) was 4.19 out of 6 (SD = 1.1, n = 60), indicating that student perceptions of the game were generally positive. The open-ended items were scored for emerging themes. In regards to the item, "Please list at least two things you like about *Losing the Lake*," 48.3% of the participants referred to fun or interactive features of the game and 18.3% listed specific visual elements (e.g., graphs, pictures, and visuals of the lake levels lowering). In addition, 46.7% referred to new information that they learned from playing the game, e.g., "new, economical ways to save water that I never heard of like the grey water". (Because participants were asked to list two ideas, the percentages sum to more than 100%.)

DISCUSSION

Although there is ample evidence that games promote interest and motivation, the evidence that games promote conceptual understanding is scant, with very few well-controlled studies with clear learning goals (Honey & Hilton, 2012). The fact that our study employed a randomized control group and demonstrated some degree of conceptual development is therefore notable, as summarized below.

The *Losing the Lake* game resulted in increased student knowledge, as displayed by higher scores (compared to the control group) on both objective and constructed response items. According to criteria proposed by Cohen (1988), the effect sizes were medium (> 0.5) for the former, and large (> 0.8) for the latter. The increase was generally maintained on a delayed posttest, which is somewhat impressive given the short engagement time playing the game. (Although the retention interval tested was only about 11 days, the results do indicate that much of the content learned became consolidated into students' long-term memories.) The increase was particularly prominent on items related to the concept of water flow (the "water we use" comes from Lake Mead and the Rocky Mountain snowpack and is returned to Lake Mead), supporting our claim that a local water-theme is a meaningful and productive concept to frame the learning environment. Although water is a "local topic," it is also a general one because many areas of the world are now experiencing drought. The *Losing the Lake* game can be useful educationally in various locales as a case study in the nature of drought, climate change effects, and water conservation practices.

In relation to water conservation, the *Losing the Lake* game increased knowledge regarding conservation practices (e.g., the importance of covering swimming pools), but not on all productive conservation options; this may have been partially due to the fact that the game only provided informative feedback on the options that the user chose. Finally, there was increased knowledge on a couple items related to climate (e.g., how it differs from weather). Prior research has shown that the misconception that climate and weather are the same thing is widespread and ingrained (Gowda, Fox, & Magelky, 1997; Lombardi & Sinatra, 2012). Weather is something that we experience daily, whereas the concept of climate is long-term and more abstract. The fact that playing the *Losing the Lake* game helped address this misconception is therefore notable. Emphasizing the concept explicitly and in large type ("Climate Change. 30 Years") and emphasizing a long-term perspective (e.g., recession of glaciers over the last 100 years) may have contributed to the effect.

Playing the game also resulted in some increase in student interest, particularly on topics related to water flow and conservation. This result also supports the conclusion that learning about "water impacts" can be an effective entrée to learning about climate change. The game was designed to address household water conservation first and then to progress to issues of greater complexity and abstraction (community, region, and global climate). Many of the learning and interest gains pertained to concrete issues within students' immediate realm of experience (e.g., the household) and this result is consistent with prior research and recommendations regarding teaching about local and personally relevant impacts of (and responses to) climate change (c.f. Anderson, 2012). Although the theme is of local relevance, climate-related drought is a problem in many parts of the world, and the *Losing the Lake* game can be used both as a case study and as a way of teaching about water conservation practices (and about climate change).

Conceptual development regarding water

In playing *Losing the Lake*, students appeared to have some difficulty with items addressing complex relationships, for example how earlier Spring snowmelts would result eventually in reduced—not increased—lake water levels through, for example, increased evaporation. We suspect that while the game addressed these relationships, students need more supplementary instruction and time to process how the various knowledge pieces learned from playing the game fit into a coherent system.

On the other hand, playing the game (even once) did appear to create some conceptual development. As shown in Table 10, there were significant gains on items pertaining to water flow, specifically where drinking water comes from (the Rocky Mountains snowpack) and where it goes when residents are done with it (back to the lake, unless recycled for outside use as grey water). In a prior study that was used to inform our game design (Nussbaum, Sinatra, & Owens, 2012), we found that even college undergraduates had little idea as to the source of their drinking water. Water is essential for life, however, so it is understandable that students who played the *Losing the Lake* game became curious about these issues. Furthermore, the game appeared to help users develop a basic understanding of water flow loops. Although such an understanding does not necessarily involve interaction effects or significant feedback effects, it does lay the foundation for developing more sophisticated concepts through additional instruction tied to the game. We argue that what is innovative about our game is not the technology per se but the conceptualization that it helps develop related to water use and sustainability.

LIMITATIONS AND CONCLUSION

This study had some limitations, particularly in regards to external validity. The game was evaluated in only two seventh-grade classrooms. The results could very well differ with students with different amounts and types of background knowledge, at different grade levels, or at different geographic locations. Future research should address these issues. Another limitation of the study is that students played the game at different points in the curriculum (at the beginning of a unit on climate in one school versus right after such a unit in the other school). Although in both schools there was more growth on the objective test items and conservation item in the treatment groups than in the comparison groups, future research should address which sort of curriculum alignment is preferable.

Another topic for future research is the utility of using the game to educate preservice or in-service science teachers about water resources and climate change. Many science teachers did not learn about these topics during their formal education (NRC, 2011) and instructional modules such as *Losing the Lake* could be especially valuable in enhancing their pedagogical content knowledge. In one study, Owens, Rehmat, and Nussbaum (2013) examined the use of *Losing the Lake* in a preservice elementary science course, and the teacher candidates found the game informative and engaging. We note that interesting and unusual curriculum materials usually are in short supply, and our game was eagerly embraced by the participating teachers in this study and the one reported on in the present article.

In closing, we note that the National Research Council (NRC, 2011), in their comprehensive review of climate change education, identified a need for more cross-disciplinary efforts that combine the teaching of scientific content knowledge with behavioral change strategies. (These behavioral change strategies encompass the disciplines of psychology and economics.) Although we did not measure the effect of *Losing the Lake* on behavior, *Losing the Lake* does address knowledge of productive conservation strategies. Education strategies need to be action oriented, as the NRC concluded that most individuals desire guidance on what they can do personally and immediately to counter environmental threats. Enhancing individuals' self-efficacy promotes learning and motivation (Moser & Diller, 2007). Nonetheless, science instruction typically focuses on content knowledge, either directly or through inquiry, rather than behavior. The *Losing the Lake* game, with its continual focus on water conservation, is one attempt to address this need while simultaneously teaching about some of the causes and effects of climate change through a water-based theme.

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APPENDIX

Losing the Lake – pre/post assessment objective items

True / False questions (7):

<u>Directions</u>: You will be asked seven true /false questions to determine your knowledge about the greenhouse effect and climate change. Please choose the answer that **best** fits the question.

1. The greenhouse effect and the ozone layer are basically the same. T or *F
2. Climate change and changes in weather are the same. T or *F
3. Over the past 100 years global temperatures have increased. *T or F
4. Humans cannot survive on Earth without the greenhouse effect. *T or F
5. Human activities produce greenhouse gases. *T or F
6. Requiring everyone in the community to cover their swimming pool would save very little water. T or *F
7. Resorts and casinos waste a large amount of water. T or *F

Multiple-choice questions (13):

<u>Directions</u>: You will be asked thirteen multiple-choice questions to determine your knowledge about water conservation, climate change, and their effect on Lake Mead. Please choose the answer that **best** fits the question.

1. There are ways to conserve water at home. Some ways save more water than others. Which of the following is the best way to conserve water at home?

a) Stop washing the family car at home.
b) Replace your old washing machine with an energy and water-efficient one.
c) Install low-flow faucets in your home.
d) *Replace lawns with desert landscape.

2. There are ways to conserve water within your community. Some ways save more water than others. Which of the following is the best way to conserve water within your community?
a) Reduce watering golf courses in the area.
b) Shut down any outside casino fountains.
c) *Raise water prices.
d) Require everyone in the community to cover their swimming pools.

3. Which of the following options would save the most water?
a) Planting trees.
b) Not washing cars at home.
c) *Using grey water systems.
d) Taking shorter showers.

4. What happens to the water that we are finished using in our homes?
a) It is returned into the ground.
b) It evaporates.
c) *It is returned to Lake Mead.
d) It flows through sewer systems.

5. Grey water systems recycle water that comes from:
a) rain.
b) *bathing.
c) manufacturing.
d) toilets.

6. What has the greatest effect on water levels in the Colorado River?
a) *The amount of snow in the Rocky Mountains.
b) The amount of snow in the Sierra Nevada Mountains.
c) The amount of rain in the area.
d) The amount of water flowing into the Colorado River from other rivers.

7. Most of the water from Lake Mead is used for __________.
a) everyday things in homes.
b) *growing crops.
c) watering golf courses and lawns.
d) drinking.

8. If Lake Mead water levels decline below 1,000 feet above sea level, what will then happen?
a) Emergency water allocations will go into effect.
b) *We will no longer be able to pump water from the lake.
c) Hoover Dam will no longer be able to generate electricity.
d) Swimming and fishing will no longer be allowed at the lake.

9. Having cities cut back 20% on their water use is estimated to delay Lake Mead water levels from declining below 1,000 feet (above sea levels) for how many years?
a) 1
b) 3
c) *5
d) 7
e) 10

10. Which of the following determines how much water Nevada can use from Lake Mead?
a) *The Colorado River Compact of 1922.
b) The Southern Nevada Water Authority.
c) The United States Bureau of Reclamation.
d) Nevada State Legislature.

11. If climate change causes an increase in average temperature of the area, what happens to the water in Lake Mead?
a) Nothing because higher temperatures will not affect water levels.
b) Nothing because the climate is not changing.
c) *The water in Lake Mead will lower due to less snowpack and therefore, less water flowing into the Lake.
d) The water in Lake Mead will rise due to the melting of the snowpack and therefore, more water flowing into the Lake.

12. Which of the following is a greenhouse gas?
a) Carbon monoxide.
b) Oxygen.
c) *Carbon dioxide.
d) Hydrogen.

13. Which of the following most contributes to an increase in greenhouse gases?
a) *Car emissions.
b) Ozone hole.
c) Smog.
d) Chopping down trees.