DESIGN AND EVALUATION OF THE MAKAHIKI OPEN SOURCE SERIOUS GAME FRAMEWORK FOR SUSTAINABILITY EDUCATION

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ABSTRACT

Sustainability education and conservation have become an international imperative due to the rising cost of energy, increasing scarcity of natural resource and irresponsible environmental practices. This paper presents Makahiki, an open source serious game framework for sustainability, which implements an extensible framework for different organizations to develop sustainability games. It provides a variety of built-in games and content focused on sustainability; game mechanics such as leaderboards, points, and badges; a variety of common services such as authentication, real-time game analytics and ability to deploy to the cloud, as well as a responsive user interface for both computer and mobile devices. The successful implementation of six sustainability educational games in different organizations provides evidence regarding the ability to customize the Makahiki framework successfully to different environments in both organizational and infrastructure aspects. A serious game stakeholder experience based access method (SGSEAM) was used to formally evaluate Makahiki in order to understand the strengths and weaknesses of Makahiki as a useful serious game framework for sustainability.

KEYWORDS

Sustainability Education, Serious Game, Gamification, Cloud, Evaluation

1. INTRODUCTION

The rising cost, increasing scarcity, and environmental impact of fossil fuels as an energy source makes a transition to cleaner, renewable energy sources an international imperative. Moving away from petroleum is a technological, political, and social paradigm shift, requiring citizens to think differently about energy policies, methods of generation, and their own consumption than they have in the past. Unfortunately, unlike other civic and community issues, energy has been almost completely absent from the educational system. To give a sense for this invisibility, public schools in the United States generally teach about the structure and importance of our political system (via classes like "social studies"), nutrition and health (through "health"), and even sports (through "physical education"). But there is no tradition of teaching "energy" as a core subject area for an educated citizen, even though energy appears to be one of the most important emergent issues of the 21st century.

On the other hand, energy and water competitions or challenges have been introduced to college dormitories and residential homes as ways to facilitate and incentivize resource reduction to achieve sustainability goals. A survey by Hodge (Hodge 2010) found that there are 163 college residence hall energy competitions taking place or being planned for the 2010–2011 academic year in North America to engaging students in sustainability issues. Hodge found that the average reduction in electricity use during these competitions is 9%. In 2014, 109 schools participated in the Campus Conservation Nationals (CCN) (Lucid Design Group 2011), a nationwide electricity and water use reduction competition for colleges and universities. Overall, the competition resulted in 4.5% average electricity competition reduction at the building level, with the top 10 schools achieving reductions ranging from 11% to 24%.

Another emergent issue is the explosive spread of game techniques, not only in its traditional form of entertainment, but across the entire cultural spectrum. The adoption of game techniques to non-traditional areas such as finance, sales, and education has become such a phenomenon that the Gartner Group included "Gamification" (Deterding 2011) on its Hype List.

This paper describes Makahiki, an open source serious game framework for sustainability education and conservation, in which we attempt to create synergy between these two emergent issues. The result of over three years of research and iterative development, Makahiki explores one section of the design space where virtual world game mechanics are employed to affect real world energy behaviors. The goal of the Makahiki project is to provide a framework for organizations to learn to not just affect energy behaviors during the course of the game, but to produce long lasting, sustained change in energy behaviors and outlooks by participants.

We initially used Makahiki to create an energy challenge called the Quest for the Kukui Cup (hereafter, the Kukui Cup) for approximately 1,000 first year students living in four residence hall towers at the University of Hawaii in 2011. During the three weeks of the competition, over 400 of the eligible students played the game, for a total of 850 game play hours. The game mechanics were designed to create a self-reinforcing *virtuous circle* between the real world and virtual world activities. The challenge was well received and has been repeated in academic years 2012 and 2014 at the University of Hawaii. In addition, Makahiki, as a serious game framework, has been used in several organizations including Hawaii Pacific University and the East West Center, an international education institute in Hawaii, to implement their own version of the Kukui Cup serious game.

In order to assess a serious game framework such as Makahiki, it is important to assess the serious games the framework produces. One fundamental question in evaluating a serious game is the extent to which the game achieves its "serious" purpose. This is quite different from the evaluation of traditional entertainment games. SGSEAM (Serious Game Stakeholder Experience Assessment Method) is an assessment method for assessing the strengths and weaknesses of a serious game framework, with respect to the experiences of different stakeholders in a serious game lifecycle (Xu 2013).

In this paper, we detail the innovative features of Makahiki framework, along with our experiences using them to implement several serious games related to sustainability education and conservation in different organizations. The application of SGSEAM to Makahiki is also described to provide insights into the strengths and weaknesses of Makahiki as a serious game framework for sustainability.

2. RELATED WORK

Our research draws on previous work done in the areas of energy behavior research, energy competitions, gamification, and serious games.

To reduce energy consumption, providing energy feedback is a critical foundation. Darby's survey of energy consumption studies from the past three decades found that consumption in identical homes could differ in energy use by a factor of two or more depending on the behavior of the inhabitants (Darby 2006). Another survey of energy feedback conducted by Faruqui et al. found that residents that actively used the in-home displays with near-real-time feedback averaged a 7% reduction in energy usage (Faruqui 2009). Darby also points out that feedback alone is not always enough: other factors such as training could lead to higher rates of energy conservation (Darby 2000).

Energy competitions or challenges have been introduced to college dormitories and residential homes as ways to facilitate and incentivize energy reduction. Petersen et al. describe their experiences deploying a real-time feedback system in an Oberlin College dorm energy competition in 2005 that includes 22 dormitories over a 2-week period (Petersen 2007). Web pages were used to provide feedback to students. They found a 32% reduction in electricity use across all dormitories. The Building Dashboard (Lucid Design Group 2008), developed by Lucid Design Group, is used to support Oberlin's dorm energy competition, as well as the Campus Conservation Nationals, a nationwide electricity and water use reduction competition on college campuses (Lucid Design Group 2011). The Building Dashboard enables viewing, comparing and sharing building energy and water use information on the web in compelling visual interface, but the cost of the system creates the barrier for wider adoptions. In addition, the building dashboard solutions focus on providing energy information as a passive media. There is little interaction between participants and the system.

Games on the other hand, have been shown with great potential as successful interactive media that provide engaging interfaces in various serious contexts (McGonigal 2011, Reeves 2009). Priebatsch attempts to build a game layer on top of the world with his location-based service startup (Priebatsch 2010).

Reeves et al. described the design of Power House, an energy game that connects home smart meters to an online multiple player game with the goal to improve home energy behavior (Reeves 2011). In the game, the real world energy data are transformed into a "more palatable and relevant form of feedback", and players may be incentivized by the in-game rewards to complete more energy-friendly real-world behaviors.

ROI Research and Recyclebank launched the Green Your Home Challenge as a case study of employing gamification techniques online to encourage residential green behavioral changes offline (Haiges 2011). Working with Google Analytics, the results show a 71% increase in unique visitors and 97% of participants surveyed said that the challenge increased their knowledge about how to help the environment.

The blending of real and virtual worlds has been explored in broader contexts. McGonigal designed the award winning serious Alternative Reality Game (ARG) "World Without Oil" (Electric Shadows 2010) and later "Evoke" (World Bank 2010) with the goal to empower people to come up with creative solutions to our most urgent real-world problems. ARGs have also been used to support learning. Connolly et al. discuss the development of an educational ARG to motivate secondary school students across Europe to learn foreign languages (Connolly 2009). The results of the pilot run of the game in 2009 indicated that 92% of students felt the game motivated students to learn a second language. One of problems the team identified is the limitation of Moodle platform the game is based on.

The report of the ARGOSI project provides insights to the use of ARGs in game based learning and the challenges in the field of higher education (Whitton 2009). The pilot was run at the University of Bolton with the aim to provide an engaging alternative to traditional methods of introducing students to university life. The overall up-take of the game was fairly low with only 23 active players out of 173 total. The project identifies a number of questions surrounding educational ARGs, such as motivation, relationship to curriculum, marketing and timing. The report suggests that a complete ARG model may not be appropriate for wholesale learning, but there is certainly potential in using game elements.

Game frameworks (also known as game engines) (Sherrod 2006) are "comprised of a collection of different tools, utilities, and interfaces that hide the low-level details of the various tasks that make up a game". One of the benefits of using a game framework is that, if correctly designed, it will provide useful and reusable "building blocks" with which to develop a variety of games. Similarly, serious game frameworks also provide building blocks that enable the serious game developer to focus more time and thought on content and results instead of on the technical details and infrastructure for creating the serious game.

Building Dashboard is commercial platform that "enables energy reduction competition and empowers building occupants to become active participants in energy management" (Lucid Design Group 2008). Building Dashboard is similar to Makahiki that they are both frameworks for supporting sustain- ability competitions, but the cost of Building Dashboard as a commercial system creates a barrier to wider adoption. In addition, the Building Dashboard solution focuses on providing energy in- formation as a passive media. Besides a scoreboard, there is little interaction between participants and the system. There are no game elements other than providing a scoreboard to display the ranking of the competing teams, moreover, there is no individual points or ranking. Unlike Makahiki, Building Dashboard does not have the concept of individual registered player account and personalization, thus it does not have the capability to provide the evidence of individual player engagement.

De Freitas and Oliver (Freitas 2006) point out that there are few frameworks to support the evaluation of serious games. They introduce a four dimensional framework for evaluating educational games and simulations. The framework consists of: the context, the pedagogy, the representation, and the learner (or player).

This approach focuses on evaluation of a single serious game, as opposed to a serious game framework. There exist some general purpose assessment tools such as GEQ (Game Engagement Questionnaire) (Brockmyer 2009) and QUIS (Questionnaire for User Interaction Satisfaction) (Harper 1993) that are used for measuring game engagement and user interactions.

SGSEAM (Xu 2013) identifies the most important stakeholders of a serious game framework and provides a method for gaining insight into the strengths and shortcomings of the framework with respect to each stakeholders' needs. SGSEAM identifies the major stakeholders whose experiences affect a serious game framework as a software infrastructure as: players, system admins, game designers, game managers and game developers. For each stakeholder, multiple in-vivo and in-vitro assessment approaches can be used, depending on the resources available. The more approaches applied, the higher one's confidence in the accuracy of the assessment results.

3. MAKAHIKI SYSTEM DESIGN

Makahiki is an open source "serious game framework for sustainability". It provides a framework for creating serious games for the purpose of education and behavioral change regarding energy, water, food, and waste generation and use. Makahiki intends to create synergy between the need to create knowledge and engagement regarding energy and the ability of so-called "serious game" techniques and energy feedback to create participation and engagement.

Makahiki consists of a configurable game engine that can be customized to the needs of different organizations. It includes a library of pre-built game "widgets" that implement a variety of game mechanics. Using the widgets, an organization can create a custom energy challenge in which players can compete individually and/or in teams to earn the most points by reducing their energy consumption as well as by learning about energy concepts in general.

Figure 1 illustrates a home page of the system implemented by using the Makahiki framework.

Figure 1. Makahiki home page

3.1 Architecture

Figure 2 illustrates the overall architecture of Makahiki.

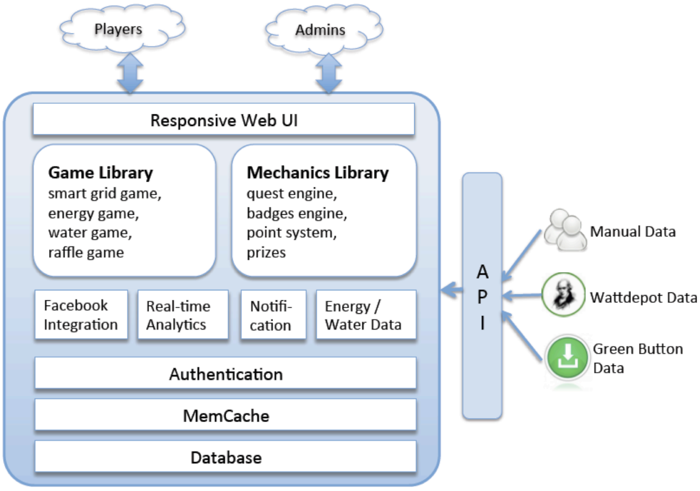


Figure 2. Architecture of Makahiki

The core component of Makahiki is a configurable game engine that can be customized to the needs of different organizations. It includes two libraries of games and game mechanics. These libraries consist of a set of pre-built “widgets”. By selecting and configuring these game and game mechanics widgets, an organization can create a customized serious game.

Makahiki interfaces with the outside environment in three different ways. First, the top side of the architecture diagram shows that Makahiki has two primary user interfaces: one for the players of the serious game, who directly interact with the game and game mechanics widgets; the other for the administrators of the system, who configure the system and monitor the real-time game analytics.

Second, the right side of the diagram illustrates that Makahiki must obtain real-world environmental data as the challenge progresses in order to provide feedback to users about the impact of their actions. In some cases, environmental data can be input automatically into the system through a combination of “smart” meters and additional services, such as WattDepot (Brewer 2011) for energy data collection, storage, and analysis). If that is not possible, then manual meters can be read by administrators on a regular (typically daily) basis and input into Makahiki using and administrator interface.

Third, the bottom side illustrates that Makahiki stores its data in a database repository (currently PostgreSQL). To reduce database access and improve performance, Makahiki provides support for caching (currently memcached).

3.2 A Library of Configurable Games and Mechanics

Makahiki builds in a set of configurable games and mechanics that can be turned on or off, or customized by the game designers to the needs of different organizations.

3.2.1 Energy and Water Game

A fundamental requirement for enabling more active participation in sustainability behavior is feedback regarding their resource such as energy and water usage. The Energy and Water game in Makahiki are implemented as the Daily Resource Goal Game. The Daily Energy Goal Game widget provides a way for players to see the outcome of the energy reduction behavior, and to make it a game by earning points from their behavior. By reducing their teams' daily energy consumption from a baseline by a set percentage, the players in the team will all earn the configured amount of points. Figure 3 illustrates this widget.

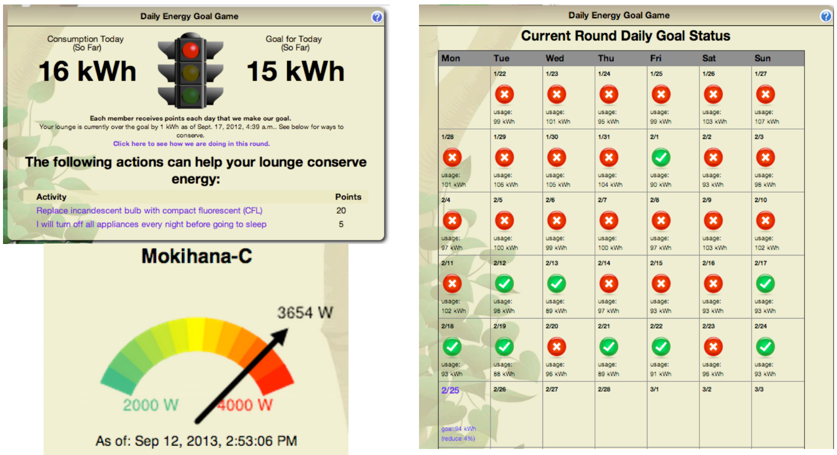


Figure 3. Daily Energy Goal Game Widget

This interface uses a stoplight metaphor to show at a glance whether or not the team is making the goal. In this case, the stoplight is green, indicating they are currently below the goal. We have found additional perspectives of the energy feedback to also be useful. One useful perspective to a team is a real time power meter visualization that shows the current power usage of a team. This visualization displays the real time power consumption which updates at a specified interval such as 10 seconds. Another useful perspective to a team is a historical, calendar-based visualization that shows the results of the energy goal game for each day of the current round.

3.2.2 Smart Grid Game

Smart Grid Game (SGG) is Makahiki's approach to support "gamified" delivery of educational experiences. Educational actions are organized into a grid of squares (hence the name "Smart Grid") and organized by category columns and levels. Players use its grid interface to discover "actions" they can perform. Successful completion of an action earns the player a variable number of points depending upon the difficulty of the action, and can potentially "unlock" additional actions and higher levels in the SGG. Figure 4 shows a typical Smart Grid Game interface for players.

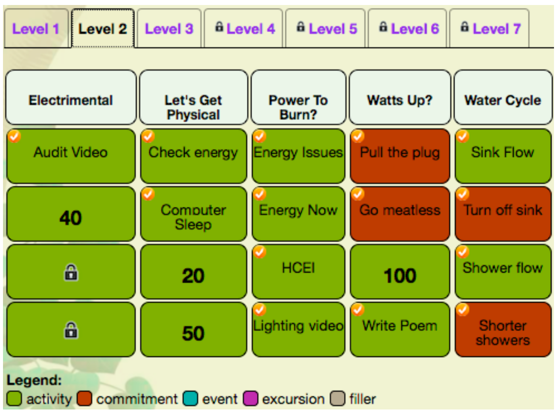
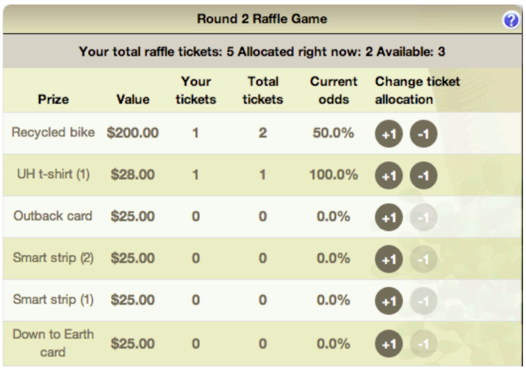


Figure 4. Smart Grid Game widget

To make your SGG more interesting to players, and more pedagogically sophisticated, Makahiki supports the definition of "path" through the educational content or actions. In most cases, when a new player sees the SGG for the first time, there should only be a few actions available to them, possibly only one. All of the rest should be locked. Makahiki provide a set of predicates that can be used to define the path. The predicates determine if an action or level is locked or unlocked for a player, which in term depends on the outcome of another action or multiple other actions.

3.2.3 Raffle Game

The Raffle Game widget provides a way to incentivize participation from all individuals, even those who are not in the running for a top prize. For every 25 points a player earns, they receive one virtual raffle ticket. Players can dynamically allocate their tickets to any raffle prizes they are interested in at any time, up to the end of the raffle. Figure 5 shows an example of the Raffle Game.


Round 2 Raffle Game

Your total raffle tickets: 5 Allocated right now: 2 Available: 3

Prize	Value	Your tickets	Total tickets	Current odds	Change ticket allocation
Recycled bike	$200.00	1	2	50.0%	+1 -1
UH t-shirt (1)	$28.00	1	1	100.0%	+1 -1
Outback card	$25.00	0	0	0.0%	+1 -1
Smart strip (2)	$25.00	0	0	0.0%	+1 -1
Smart strip (1)	$25.00	0	0	0.0%	+1 -1
Down to Earth card	$25.00	0	0	0.0%	+1 -1

Figure 5. Raffle Game widget

Raffle tickets are independent from a player's score, and allocating a raffle ticket does not affect their rank. The system provides random selection of the winner of each raffle item at the end of a round.

3.2.4 Social and Referral Bonuses Game Mechanics

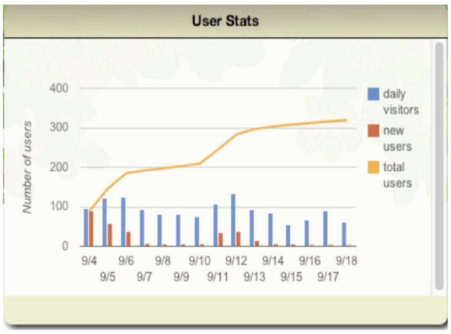
The Social and Referral Bonus widgets are the game mechanics that help encourage participation by providing additional points to players who participate in activities with other players, and facilitate the entry of new players into an energy challenge.

The social bonus is a configurable option when an action is created in the Smart Grid Game. Players earn extra points if they perform the action with another player. When a player submits a response for an action with a social bonus, the player can provide the email address of the person who jointly completed the action. Once the other player completes the action, the social bonus is awarded.

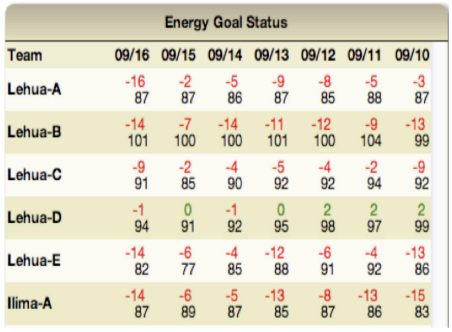
Players are led through a setup process when logging into Makahiki for the first time. One of the steps in this process is the referral bonus. If a player was referred by another player in the system, he can use this step to input their email address. Once the new player earns a certain number of points in the competition, both players are awarded a referral bonus of a configurable number of points.

3.3 Real-time Analytics

Makahiki is designed to support energy challenges involving hundreds or thousands of users lasting weeks or months. In these circumstances, effective use of the technology requires the ability to understand the state of the game, such as: Who is using it? What are they doing? What is the player response to activities, commitments, excursions, and events? Such state information is important for planning purposes, such as assessing the transportation needs for an upcoming excursion by seeing how many players signed up. It can also be used for making in-game changes to game design, such as changing the point values associated with activities to encourage or discourage participation. It can also help identify breakdowns in game play, such as significant numbers of unallocated raffle tickets indicating that users do not understand the nature of that game mechanic. To address these needs and others, Makahiki includes a variety of widgets that work together to provide high level overview of game play state to the administrators of a challenge. Figure 6 shows examples of some game analytic widgets.



(a) User Stats



Energy Goal Status

Team	09/16	09/15	09/14	09/13	09/12	09/11	09/10
Lehua-A	-16 87	-2 87	-5 86	-9 87	-8 85	-5 88	-3 87
Lehua-B	-14 101	-7 100	-14 100	-11 101	-12 100	-9 104	-13 99
Lehua-C	-9 91	-2 85	-4 90	-5 92	-4 92	-2 94	-9 92
Lehua-D	-1 94	0 91	-1 92	0 95	2 98	2 97	2 99
Lehua-E	-14 82	-6 77	-4 85	-12 88	-6 91	-4 92	-13 86
Ilima-A	-14 87	-6 89	-5 87	-13 85	-8 87	-13 86	-15 83

(b) Energy Goal Status

Figure 6. Game analytic widgets: User Stats and Energy Goal Status

3.4 Responsive mobile support

We believe that mobile support is essential for this kind of sustainability challenge, especially for the new generation players. Makahiki implemented responsive web design technology to support multiple devices to enhance the player experience. Figure 7 shows the responsive interface in Makahiki that supports both desktop view and mobile view with the same code base.

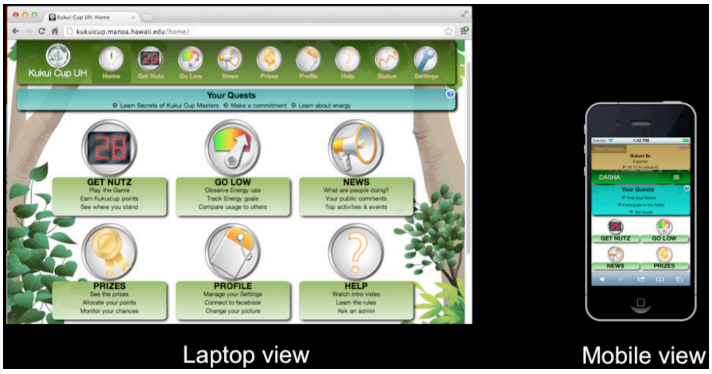


Figure 7. Responsive design supports both desktop and mobile

3.4 Cloud deployment support

Another Makahiki feature is the ability to deploy to a cloud platform such as Heroku. Cloud computing has the advantage of simplifying IT administration by eliminating the need to acquire and maintain hardware and operating system software. This also can dramatically decrease the cost of deployment. Figure 8 shows a screen shot of the Dashboard showing the 2012 East West center Kukui challenge deployed in Heroku, one cloud platform provider, and the monthly cost for this deployment.

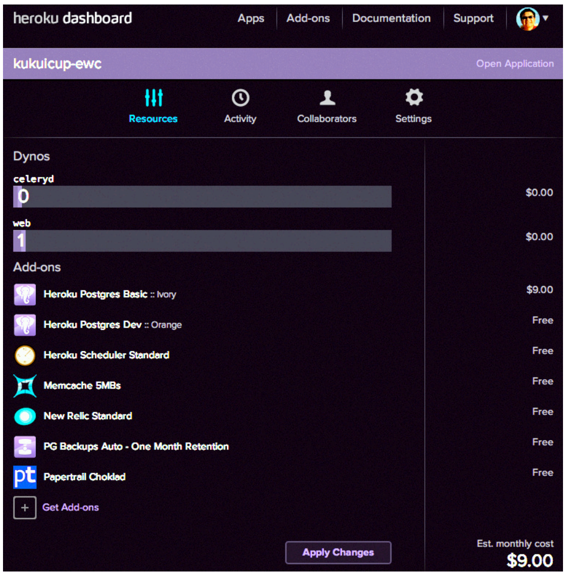


Figure 8. Heroku cloud deployment

4. EXPERIENCES WITH MAKAHIKI

We have used Makahiki to create six different energy and water serious game instances, all called "Kukui Cup" challenges. Three Kukui Cup Energy challenges were held at the University of Hawaii (UH) in 2011, 2012 and 2014 for over 1,000 first year students each year living in the residence halls. Hawaii Pacific University (HPU) held a Kukui Cup Energy challenge in 2012 and 2013 for about 200 students each year. An international organization called the East-West Center (EWC) held a Kukui Cup Energy and Water challenge for approximately 600 international residents living in their residence halls in 2012. Since the EWC residence halls did not have internet-enabled meters, resource consumption data had to be entered by the game managers manually.

Through the game interface, students learned about sustainability both online and in reality to conserve energy and water consumption and other sustainability related behaviors. The in-game survey results from the multiple UHM instances indicate that the games had positive impacts on their energy literacy, self-reported sustainability awareness and self-reported behavior changes. Both the UHM and HPU instances achieved about 30% player participation rate, which may lead to impacts to the community around the participants. The engagement metrics based on the game data from 2011 and 2012 UHM instances also indicates high levels of player engagement during the 4 weeks period.

The successful creation of these serious game instances provides evidence that Makahiki can be successfully tailored to the needs of different organizations. Among these instances, UHM and HPU used different metering infrastructure for energy data collection, EWC collected their resource data manually, and HNS did not have energy data at all. While UHM and HPU challenges involved only energy consumption data, the EWC challenge involved both energy and water consumption data. The IT infrastructure at UHM and HPU provided authentication services using CAS and LDAP, while EWC used both CAS and the built-in Django internal authentication, and HNS used only the internal authentication. Moreover, the user interface was customized to "brand" each challenge with the logo, thematic elements, and the education content of the sponsoring organizations.

Lastly, the hosting infrastructure among these instances are different in two categories: local hosting for HPU and the 2011 UHM instances, and cloud hosting for EWC, HNS and 2012, 2014 UHM instances. These two types of hosting requirements created unique challenges for Makahiki. There are different costs associated with these hosting solutions, as described in Table 1.

Instances	Hosting	Other cloud services	Duration	Cloud service cost
UHM2011	Local Mac OS server	N/A	3 weeks	N/A
UHM2012	Heroku cloud	Amazon S3, Memcache	9 months	$908
UHM2014	Heroku cloud	Amazon S3, Memcache	2 weeks	$150
HPU2012	Local CentOS server	N/A	3 weeks	N/A
HPU2013	Local CentOS server	N/A	3 weeks	N/A
EWC2012	Heroku cloud	Amazon S3, Memcache	2 weeks	$9
HNS2013	Heroku cloud	Amazon S3, Memcache	7 months	$146

Table 1. Hosting Configuration Differences between Makahiki Instances

Although there are some incurred costs in the case of hosting the Makahiki games in the Heroku cloud infrastructure, there is no need for maintaining local infrastructure, such as keeping the server running, upgrades, patching as well as locating physical space for the server. There is no need to allocate IT support staff resource to do system admin. In addition, the dynamic resource allocation capability of the cloud infrastructure provides a flexible and efficient utilization of infrastructure resources in running the competition, especially in the case of short competition duration and varying user demands during the game.

The successful use of Makahiki in the Heroku cloud platform provided a good alternative for organizations such as EWC and HNS who have less technology capacity. It also provides greater flexibility in infrastructure scaling up and down depending on the usage demand. In the context of serious games, which are often running for a period of time and have various usage demand throughout the game period, using the cloud infrastructure is a good alternative.

5. EVALUATION OF MAKAHIKI

The evaluation of Makahiki is carried out using the SGSEAM method described (Xu 2013). It includes both qualitative and quantitative sources of data regarding the system in the aspects of different stakeholders in a serious game lifecycle, as described in Figure 9.

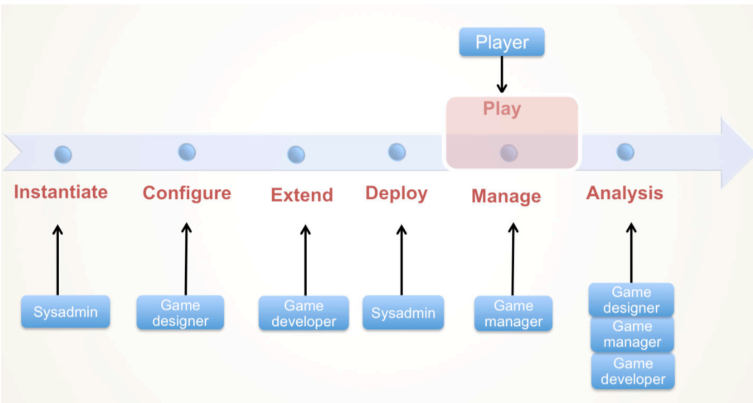


Figure 9. Serious game lifecycle using a framework

The SGSEAM assessment for Makahiki was implemented in two categories of assessment approaches. The in-vivo approaches of pre-post effectiveness study, in-game surveys, and post- hoc interviews were applied to the real-world UHM, HPU and EWC Makahiki instances. The other in-vitro approaches were applied to the UHM ICS691 serious game course as an in-lab experiment. Table 2 provides the overview of assessment for each SGSEAM stakeholders of the Makahiki framework.

Stakeholder	Assessment Approach	Participants
Players	Pre-Post effectiveness study	UHM Kukui Cup players
	Self-reported effectiveness survey	
	Self-reported usability survey	
	Engagement metrics	
System admins	In-lab installation study	UHM ICS691 students
	Post-hoc system admin interview	HPU Kukui Cup sysadmin
Game designers	In-lab game design study	ICS691 students
	Post-hoc game designer interview	HPU & EWC Kukui Cup game designers
Game managers	Post-hoc game manager interview	HPU & EWC Kukui Cup game managers
Developers	In-lab game development study	ICS691 students

Table 2. SGSEAM assessments for Makahiki

Makahiki provides custom quantitative instrumentation that enables us to track when, where, and for how long each player accessed each page of the site. Unlike generic web server logs, we could track per-player application-specific behaviors. We also gathered qualitative data through a survey that players could complete as part of a Smart Grid Game activity during the final week of the competition. The survey asked participants to provide short answers to questions regarding the way the competition and website was designed. 41 players completed this survey.

In response to a survey question asking how the player might describe the Kukui Cup, 83% said "Fun", 95% said "Educational", while 7% said "Difficult" and 2.3% said "Boring". In response to the question, "What was confusing in the website", 46% of the players said "Nothing", and 32% of the players also responded "Nothing" in response to the question, "What would you change about the website? When asked what they liked most about the website, 60% of the survey respondents said "ease of use". Instrumentation also indicates that the game was generally easy to use. 73% of the 418 players never accessed the "Help" page, and only 5% of the players sent questions to the administrators. The data bear out the success of the raffle game. Players mentioned the raffle game repeatedly as the most interesting incentive in the game, and over half the students with at least 100 points participated in the Raffle.

To assess the effectiveness of the framework for designing games that improve player literacy in sustainability, we conducted two energy literacy surveys during the 2011 Kukui Cup Challenge at the University of Hawaii at Manoa. One survey was administrated before the challenge (pre-game) and one after (post-game). 24 players completed both surveys. Out of the total 19 energy literacy questions, the average number of questions answered correctly is 7.54 before the challenge, and 8.96 after the challenge. This result indicates an 18% improvement on the energy literacy. We also surveyed non-players as a control condition, and found that their literacy did not change, indicating that the improvement in player literacy was indeed due to the game.

To assess the effectiveness of the framework for designing games that produce positive change in sustainability behaviors, we recorded and analyzed energy consumption data before, during and after the challenge. Before the challenge, an energy usage baseline was established. During the challenge, compared to the baseline, 12 out of the total 20 teams reduced their energy consumption, with the highest reduction of 16.1%. However, 3 teams actually increased their energy consumption, with the highest increase of 11.7%. Overall, the average reduction of the 20 teams was low, approximately 2%.

We also assessed player engagement of the game. We calculated a variety of engagement metrics based on the analytics data collected by the Makahiki framework. The participation rate of this challenge is 37%, which is good compared to other sustainability challenges. Over the course of the challenge, an average player spent about 27.7 minutes per day on the website. One player spent 8.5 hours on one day. There were an average of 266 activity submissions and 208 social interactions between players per day. The average number of website errors per day was 0.6.

The in-lab installation study and the post-hoc interviews were carried out to assess the experiences for the stakeholders of the serious game lifecycle besides players. They are system admins, game designers, game managers and developers.

The application of SGSEAM to Makahiki identified several strengths and weaknesses of Makahiki as a serious game framework for sustainability. SGSEAM revealed that the major strengths of Makahiki are the ability to create an engaging and effective serious game for an organization, and the ability to provide an easy-to-use interface for game designers and managers. SGSEAM revealed the major weaknesses of Makahiki are difficulty in developing new enhancements to extend the framework from a game developer's perspective, difficulty to integrate external services such as LDAP and email server from a system admin's perspective, and the lack of WYSIWYG content authoring tool from a game designer's perspective.

6. CONCLUSION

The Makahiki research presents an innovative information technology infrastructure that can support effective and efficient development of serious games for sustainability education and conservation that can be used by different organizations. Its tailorability and game analytics also provides a useful platform for research on gamification, sustainability education, and behavior change. Makahiki is an open source system hosted on GitHub (Makahiki 2015) with less restricted MIT open source license. The application of SGSEAM to Makahiki has effectively identified several strengths and weaknesses of Makahiki as a serious game framework for sustainability.

Our research suggests that several enhancements to the Makahiki framework would be useful. One is real-time player awareness. It is not possible currently in Makahiki to know who is currently "on line" and playing the game. Creating this awareness opens up new social gaming opportunities (performing tasks together), new opportunities for communication (chat windows), and potentially entirely new games (play "against" another online player).

Makahiki currently ships with over 100 possible "actions" already developed for the Smart Grid Game. However, the content is intimately tied to the Smart Grid Game implementation. An enhancement is to provide a "content management system" for "actions", separating "content" from the "presentation", thus new contents can be added and more games can be developed using this content library.

We are also exploring a future direction involving the development of a consortium of organizations in order to scale the use of the Makahiki framework in new settings. Moving outside of the context of either Hawaii or college-aged players will necessitate development of significant new forms of content, as well as new game mechanics.

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REFERENCES

Sherrod, A. 2006. Ultimate 3D Game Engine Design & Architecture. *Charles River Media, Inc.*, 2006.

Brockmyer, J. et al. 2009. The development of the game engagement question- naire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology*, 45(4):624–634, 2009.

Brewer, R.S. and Johnson, P.M. 2010. WattDepot: An open source software ecosystem for enterprise-scale energy data collection, storage, analysis, and visualization. *Proceedings of the First International Conference on Smart Grid Communications*.

Harper, B. et al, 1993. Improving user satisfaction: The questionnaire for user interaction satisfaction version 5.5. In *Proceedings of the 1st Annual Mid-Atlantic Human Factors Conference*, pages 224–228.

Hodge, C. 2010. Dorm energy competitions: Passing fad or powerful behavior modification tool? Presentation at the *2010 Behavior Energy and Climate Change Conference*.

Connolly,T. et al, 2009. Arguing for multilingual motivation in web 2.0: a games-based learning platform for language learning. *European Conference on Games Based Learning*.

Darby, S. 2000. Making it obvious: designing feedback into energy consumption. *Proceedings of 2nd International Conference on Energy Efficiency in Household Appliances and Lighting*.

Darby, S. 2006. The effectiveness of feedback on energy consumption. *Technical report, Environmental Change Institute, University of Oxford*.

Deterding, S. et al, 2011. From game design elements to gamefulness: Defining "gamification". *Proceedings of MindTrek*.

Electric Shadows. 2010. World without oil, http://www.worldwithoutoil.org/metaabout.htm

Faruqui, A. et al, 2010. The impact of informational feedback on energy consumption–a survey of the experimental evidence. *Energy*, 35(4):1598–1608.

Freitas, F. et al, 2006. How can exploratory learning with games and simulations within the curriculum be most effectively evaluated? *Computers & Education*, 46(3):249– 264.

Haiges, H. 2011. Gaming for good. *Technical report, ROI Research Inc*.

Lucid Design Group. 2011. Campus conservation nationals, *http://www.competetoreduce.org/,* Lucid Design Group, Inc.

Lucid Design Group. 2008. Building Dashboard. *http://www.luciddesigngroup.com/,* Lucid Design Group, Inc.

McGonigal, J. 2011. Reality is broken: Why games make us better and how they can change the world. *Penguin Press*.

Makahiki, 2015. An open source serious game engine for sustainability. *http://github.com/csdl/makahiki*.

Petersen, J. E. et al, 2007. Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives. *International Journal of Sustainability in Higher Education*, 8(1):16–33.

Priebatsch, S. 2010. The game layer on top of the world. *http://www.ted.com/talks/seth_priebatsch_the_game_layer_ on_top_of_the_ world.html*, TED.

Reeves, B. et al, 2011. Leveraging the engagement of games to change energy behavior. *Proceedings of the CHI 2011 Workshop on Gamification*.

Reeves, B. and Read, J. 2009. Total engagement: using games and virtual worlds to change the way people work and businesses compete. *Harvard Business School Press*.

Xu, Y. et al, 2013. SGSEAM: Assessing serious game frameworks from a stakeholder experience perspective. *ACM International Conference on Gamification 2013*.

Whitton, N. 2009. Alternate reality games for orientation, socialisation and induction (ARGOSI). *Technical report, JISC*.

World Bank. 2010. Urgent evoke. *http://www.urgentevoke.com/,* World Bank Institute.