



Assessing Cognitive Development and Motivation with the Online Watershed Learning System (OWLS)

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Abstract: A recent report on *Challenges and Opportunities in the Hydrologic Sciences* by the National Academy of Sciences states that the solutions to the complex water-related challenges facing society today begin with education. The Learning Enhanced Watershed Assessment System (LEWAS) is a real-time watershed monitoring lab that seeks to address these complex-water related challenges by improving water-related education at the community college and four year university levels. The Online Watershed Learning System (OWLS), the data sharing and visualization component of the LEWAS, is an environmental exploration tool that gives users access to historical and live LEWAS data, watershed-specific case studies, and virtual tours of the LEWAS watershed. By using an HTML5-driven web interface, the OWLS interactively delivers integrated live and/or historical remote system data (visual, environmental, geographical, etc.) to end users regardless of the hardware (desktop, laptop, tablet, smartphone, etc.) and software (Windows, Linux, iOS, Android, etc.) platforms of their choice.

We have built upon a prior study that used the expectancy-value theory of motivation to show that exposure to live watershed data via the LEWAS increased students' levels of motivation. A pilot test of the OWLS has demonstrated positive learning gains in engineering seniors and was overwhelmingly viewed by students as having helped them learn hydrology concepts. The pilot test also revealed the strengths of the OWLS to be anywhere, anytime access to live system data and interactive graphical representations of the data. Using the framework of situated learning, the current research implements the OWLS as a remote lab for both freshmen community college students in general engineering courses as well as senior university students in a hydrology course. We seek to determine: (i) how the OWLS influences student learning with respect to course learning objectives, and (ii) how the use of OWLS in engineering courses impacts motivation in students. The assessment follows an experimental design with pre- and post-test questions that include both Likert-style motivation questions and concept inventory-style cognitive learning questions that have been developed by content experts for each course level and are scaled using Bloom's Revised Cognitive Taxonomy. Results from fall 2014 freshmen course are analyzed and presented and results from both levels in the spring 2015 semester will be included in the presentation.

1.0 Introduction

In 2008, the U.S. National Academy of Engineering (NAE) announced 14 Grand Challenges in engineering that are awaiting solutions in the 21st century. This list includes the challenge to "Provide Access to Clean Water"¹. Water is the critical resource for supplying food and energy, safeguarding human health and maintaining national security. Increasing pressures for water demand worldwide present challenges to scientists and engineers to attain sustainable management of water resources. A recent United Nations report projects that virtually every

nation will face a water supply problem within the next 8 years; currently more than a billion people have little access to clean drinking water, and 2 billion live in conditions of water scarcity². To address these critical issues, the NAE's "The Engineer of 2020" highlights the need for implementing ecologically sustainable practices to preserve the environment for future generations. Further, the report emphasizes that water supplies will affect the future of the world's economy and stability³. As a result, the NAE warns that unless better ways to protect and improve water supplies are found, the future looks dire for billions of people⁴.

To prepare for these challenges, the educational system must teach our youth about critical hydrology related issues and train them as future professionals who are capable of developing appropriate solutions. Two of the greatest challenges facing hydrology education in the 21st century include providing student-centered activities and field experiences in the classroom⁵ and replacing historical stationary data with real-time, dynamic, and temporally and spatially variable hydrologic systems⁶⁻⁷. Replacing traditional teaching methods with student-centered experiences that incorporate non-stationary data will require advances in classroom tools and teaching methods that capture the attention of students through an active learning experience. Incorporating student-centered learning through virtual and remote laboratory experiences⁸⁻¹⁰ that situate users in a remote hydrologic site is a common method for achieving this goal¹¹⁻¹².

This study investigates such an educational tool by determining the impact of the Online Watershed Learning System (OWLS) on student learning and motivation in university and community college classrooms. The OWLS is an online tool that broadcasts real-time, high-frequency environmental data (flow, water quality and weather) from the Learning Enhanced Watershed Assessment System (LEWAS) located in a watershed on the campus of Virginia Tech. The LEWAS is an environmental monitoring lab that collects water quality, flow and weather data in high-frequency (1-3 minute) intervals in a stream that drains a 2.8 km² urban watershed. The OWLS allows users to remotely explore the watershed through access to real-time data, geographic watershed tours, and watershed-specific case studies. Students use the OWLS to participate in hands-on remote lab activities that virtually situate the students from the classroom into the field. This study seeks to enhance student learning and motivation by incorporating the OWLS activities into the curriculum to engage students in active learning while supporting course objectives in university and community college classrooms. This study focuses on how the OWLS influences student learning with respect to course objectives mapped to learning outcomes as defined by ABET a-k criteria¹³ and influences student motivation using the MUSIC model¹⁴ to address the following research questions: (1) How does the OWLS influence engineering students' abilities with respect to course learning objectives?; (2) How does engineering students' use of the OWLS relate to their motivation levels?; and (3) How does student learning and motivation vary across institutional contexts (i.e., university vs community college) in students that are exposed to the OWLS?

The outcomes of this study will ultimately result in a greater understanding of how remote lab technologies can bring field experiences into the classroom via online access to dynamic real-world data to enhance student learning and motivation in hydrology education, thus addressing one of the grand challenges facing hydrology education in the 21st century of providing real-time, dynamic, and temporally variable data⁶. This study also provides insights into how technologies such as the OWLS can be used to support classroom learning objectives that map to ABET criteria.

The focus of this paper is on the background, theoretical framework, and methodological approach of the study, with results presented from a pilot test conducted in the community college courses during the fall 2014 semester. Specific details on the design of the LEWAS system and the OWLS and results from the first pilot test in the hydrology course during the spring 2014 semester can be found in previous publications¹⁵⁻¹⁶. The presentation associated with this paper will also contain the final results from the OWLS implementation in the spring 2015 university and community college courses.

2.0 Background

An advantage of the LEWAS is the ability to collect, store, and transmit data in real-time, which can be displayed through an environmental virtual or remote lab, such as the OWLS, where students can explore the environment, case studies, and live data. Virtual labs are software that simulate the real environment, whereas remote labs are labs where experiments are conducted remotely across the Internet. Virtual labs have been shown to be effective in improving student understanding of important engineering concepts¹⁷⁻¹⁹. For example, researchers at UCLA found that students perceived learning gains when using the Interactive Site Investigation Software (ISIS) to perform virtual field work such as constructing wells, collecting groundwater samples, submitting samples for laboratory testing, and executing hydraulic transport experiments¹⁰. Applications of remote labs in engineering education have also been shown to improve student understanding of engineering concepts²⁰⁻²¹ and are comparable to hands-on labs^{8-9,22}. For example, researchers at Rutgers University found that there was no difference in educational outcomes between students who participated in a remote lab versus an in-person lab⁹. The OWLS uses components of both virtual labs (students can virtually explore a simulated environment through geographic representations) and remote labs (students can choose which parameters they want to measure) to give users a unique educational experience.

Pilot tests of the OWLS have been implemented in two freshman level introduction to engineering courses at Virginia Western Community College and into a senior-level hydrology course at Virginia Tech during the 2014 school year. The OWLS was implemented into each course using classroom modules that are based upon previous work integrating real-time, high-frequency LEWAS data into the classroom^{12, 23-25}. These previous studies found that students who were exposed to real-time environmental data had improved levels of motivation²³ and that students who participated in LEWAS-based modules that used high-frequency data experienced significant learning gains¹⁶.

Using the OWLS, this study seeks to build upon previous work by providing an interactive online watershed education tool that gives students access to real-time, high-frequency environmental data from the LEWAS field site, as well as case studies, interactive maps, and other educational tools from within the system. Students in each course participate in modules that include in-class and take home exercises that use all aspects of the OWLS to solve problems related to course objectives. During the pilot test, real-time data were not available within the OWLS so the students used historical data from a set of storm events on a 4-day loop; however, it is expected that real-time data will be available for the spring 2015 courses.

3.0 Theoretical Framework

In order to evaluate these research questions, multiple theoretical frameworks will be required. From the analysis of prior studies, it becomes apparent that the learning environment impacts student learning. This suggests the use of situated learning, which argues that knowledge is “distributed among people and their environments”²⁶. These two sub-areas form the sociocultural and sociocognitive traditions of situated learning, respectively²⁷. Within the sociocognitive tradition, remote labs utilize digital technology to virtually situate users at remote field sites. In this research, the framework of situated learning is used to assess the impact of the remote learning environment on student learning. The learning community impact has been kept for future work.

Concerning the measurement of student learning outcomes, using Bloom’s Revised Cognitive Taxonomy continues previous research completed by the LEWAS Lab team. According to the National Academy of Sciences, “Ensuring clean water for the future requires an ability to understand, predict and manage changes in water quality.”¹ These three abilities can be aligned with levels 2 (understanding), 5 (evaluating) and 6 (creating) of Bloom’s revised cognitive taxonomy, respectively²⁸⁻²⁹. Wagenet et al.³⁰ used Bloom’s original cognitive taxonomy to assess individuals’ learning of water sustainability topics. Concept inventories provide one convenient method for quantitatively assessing students’ learning relative to Bloom’s Revised Cognitive Taxonomy³¹. Wagenet et al.’s questions can be used as concept inventory questions for life-long learners, and Zint and Kraemer³² have developed concept inventory questions about coastal watersheds for middle and high school students. However, watershed-focused concept inventories at the undergraduate and graduate level have not been found. As an alternative to concept inventories, Marshall, Castillo and Cardenas³³ used scoring rubrics to generate numerical scores from qualitative writing for physical hydrology students. Within the current study, content experts produce concept inventory questions at the undergraduate level based on the levels of Bloom’s Revised Cognitive Taxonomy.

Measurement of student motivation outcomes is assessed using Jones’ MUSIC Model of Academic Motivation¹⁴. This model consists of the following five primary components of motivation: 1) eMpowerment, 2) Usefulness, 3) Success, 4) Interest and 5) Caring. Empowerment relates to self-determination theory, which states that people are more motivated if they perceive that they have control over some aspects of their learning³⁴⁻³⁶. Usefulness relates

to the future value that students perceive in what they are learning. Students who have clearly defined long-term goals and who believe what they are learning aligns with those goals are more motivated³⁷⁻³⁸. Utility Value from Eccles and Wigfield's expectancy-value theory of motivation is also related to usefulness³⁹⁻⁴⁰. Success is related to many theoretical frameworks including self-efficacy theory⁴¹⁻⁴², self-concept theory⁴³⁻⁴⁵, self-worth theory⁴⁶, goal orientation theory⁴⁷ and the intrinsic and attainment values in expectancy-value theory. These theories deal with such aspects of success as the perceived importance and enjoyment of succeeding, belief in one's ability to succeed and setting goals to achieve. Self-efficacy theory was used by Kamarainen et al.⁴⁸ in their augmented reality lab. Interest can be assessed using Hidi and Renninger's⁴⁹ four-phase model of interest, which increases from fleeting situational interest to long-term internalized interest. Bloom's affective taxonomy²⁸ is another important scale of measuring interest in a topic. Finally, caring contains two major components, i.e. students' personal interactions with faculty and students' perceived level of caring by faculty⁵⁰.

4.0 Experimental Design

A mixed methods approach was chosen for the study because it allows for the most complete answer to the research questions through the combination of complementary approaches⁵¹. This study is a multi-modal design with two phases as illustrated in Figure 1. Phase 1 is a concurrent embedded design in which the quantitative analysis is given priority. This is followed by data analysis that informs an explanatory sequential qualitative phase 2. A concurrent design is chosen in phase 1 because the constrained time within a course does not allow for a sequential survey assessment design. However, a focus group in phase 2 held at the conclusion of the semester serves as an explanatory sequential follow-up to obtain thick-descriptions from students. The pilot test during the fall 2014 semester that is presented in this paper only implemented phase 1 of the assessment due to time and resource restrictions. Current work in the spring 2015 semester will implement the entire mixed methods design (phase 1 and phase 2) into the courses.

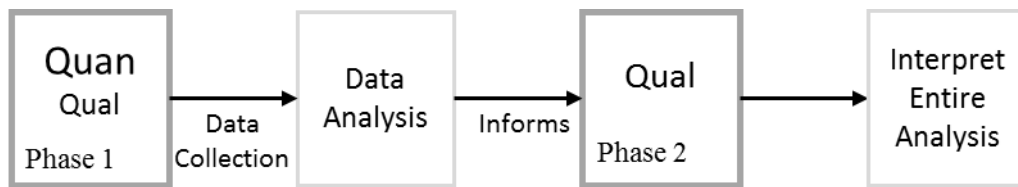


Figure 1. Mixed Methods Design

4.1 Phase 1 Quantitative Methods

Pilot studies of the OWLS were conducted during the spring and fall 2014 academic semesters in the university and community college courses, respectively. The OWLS was pilot tested in the senior level hydrology course during the spring 2014 semester (n=30) using a *one group pretest-posttest* design. Students in this pilot test used the OWLS to complete a take-home

assignment and were asked questions afterwards in a survey to determine student-perceived effectiveness of the OWLS in helping them learn. A pilot test for OWLS implementation into community college courses was held in the fall 2014 semester using a *one group posttest-only* design. During this course, students were given a posttest assessment (n = 27) after their use of the OWLS, and analysis of the results from this pilot test are the focus of the assessment in this paper. This study is also implementing a *one group pretest-posttest* study into the spring 2015 hydrology course and a *pretest-posttest control-group* study into the community college spring 2015 courses. Assessment from the spring 2015 courses is not included in this paper but will be included in the associated presentation. An outline of the OWLS implementation into each institution is illustrated in Table 1.

Table 1. OWLS Quantitative Implementation Outline

Implementation	Experimental Design
University Spring 2014 (pilot)	One group pretest-posttest
Community College Fall 2014 (pilot)	One group posttest only
University Spring 2015	One group pretest-posttest
Community College Spring 2015	Pretest-posttest control group

There are multiple limitations to the experimental designs in each course. For each experimental design, non-random sampling may introduce systematic errors such as selection bias, which may undermine the external validity of the assessments. In addition, the sample of students in each experimental design contains students from the same course and will not be statistically representative of a greater population of engineering students, therefore limiting the generalizability of the results.

To assess how student learning is impacted by the OWLS, the pretests and posttests in the pilot tests focused on student perceptions of learning, while the assessments in the spring 2015 courses are focusing on students' conceptual knowledge. Testing student perceptions in the pilot studies provides valuable feedback on the student perspectives of using the OWLS, which are then used to improve the system. Previous work has shown that student perceived learning in senior-level hydrology students and freshman community college students improves when they are exposed to real-time, high-frequency watershed data from the LEWAS system¹⁶. Questions from these previously developed assessments have been used to create a concept inventory, which contains multiple choice questions that map classroom objectives to learning outcomes as defined by ABET a-k criteria. The questions from this concept inventory are being used for the spring 2015 assessments.

To test how the OWLS affects engineering students' motivation levels, the students in the fall 2014 pilot test were given a posttest based on the MUSIC model of motivation¹⁴. This assessment model tests students' level of motivation based upon five recommended components

that an instructor should consider when designing instruction: eMpowerment, Usefulness, Success, Interest, and Caring. The assessment instruments are modified by changing the questions to reflect the student’s use of OWLS according to the recommendations by Jones¹⁴ in order to test specifically how use of the OWLS by engineering students impacts their motivation levels. The questions based on the MUSIC model are being used in the spring 2015 assessments.

Quantitative data and analysis (discussed later in the Data Analysis section) results in statistics that provide insights and answers to the research questions in this study. However, this method alone has limitations as it restricts the analysis to the chosen categories and variables and may not properly reflect the students’ experiences and understandings. Qualitative methods on the other hand can take on a role of discovery and exploration to develop constructs, categories, or theories not hypothesized in the experimental design⁵¹. The following qualitative analysis seeks to provide corroborating data to address the limitations to validity and the transferability of the quantitative results.

4.2 Phase 1 Qualitative Methods

The qualitative design in phase 1 includes open-ended questions that are given alongside the quantitative questions in the surveys. Table 2 contains the outline of the qualitative methods that are used throughout the study. In the pilot tests, surveys that contained open ended questions were implemented as pretests and posttests. The surveys being used in spring 2015 studies contain some of the same questions from the pilot tests, but they also contain new questions based on analysis and feedback from student responses in the pilot tests.

Table 2. OWLS Qualitative Implementation Outline

Implementation	Data Collection
University Spring 2014 (pilot)	Survey
Community College Fall 2014 (pilot)	Survey
University Spring 2015	Survey, Focus Group*
Community College Spring 2015	Survey, Focus Group*

**Phase 2*

To test how student learning is impacted by the OWLS, the qualitative pretest and posttest survey questions focus on students’ perceived learning. Surveys are commonly used in qualitative research within engineering education to assess participants through the use of open ended questions⁵². The open ended questions seek to gain a greater insight into what components or features of the OWLS helped the students to learn most effectively, or which components were not effective in the minds of the students. For example, a question asks, “Was the OWLS a valuable tool for learning in this course? If so, how?” This question and others seek to explain the reasons behind the trends that are observed in the quantitative data.

To test how student motivation is impacted by the OWLS, the pretest and posttest surveys also ask students open-ended qualitative questions related to their motivation within the course. Results from prior studies have shown that having access to real-time environmental data through the LEWAS lab has increased student expectancy-value motivation in multiple courses. For example, in a case study with 150 engineering freshmen at Virginia Tech in spring 2012, it was shown that having access to real-time water and weather data through the LEWAS improved students' motivation to learn about water sustainability issues²³. The surveys in this study seek to understand specifically how access through the OWLS to real-time water and weather data in addition to case studies and watershed exploration tools, effects student motivation. For example, an open ended question asks "What value, if any, do you see in real-time monitoring of water quantity and quality?"

4.3 Data Analysis

Using the responses from the surveys, the qualitative data are analyzed for codes and themes. This is done by (1) familiarizing the researcher to the data through reading and re-reading the data, (2) generating initial codes, and (3) gathering the codes with the help of Nvivo software to identify potential themes⁵³. To ensure credibility of the coding process, multiple team members code the data and discuss their results among each other. Any differences in the codes and themes are discussed and reconciled through an iterative process⁵².

Data from the quantitative and qualitative surveys are compared against each other in order to expand the understanding of the research problems. By taking a mixed methods approach, multiple sources of data may lead to corroboration that produces a greater confidence in answers to the research questions; alternatively, multiple source of data may lead to divergence that would result in adjustments to insights or conclusions. In either case, results from the data analysis inform the creation of the focus group questions. Where there is significant corroboration or divergence amongst the qualitative and quantitative data that cannot be explained through the data themselves, questions will be created for the focus group to address these missing gaps.

4.4 Phase 2 Focus Group

Focus groups in phase 2 were not conducted in the pilot test, and thus no results from focus groups are presented in this paper. However, focus groups will be held separately with students in the university and community college courses at the end of the spring 2015 semester. These focus groups will attempt to gain a better understanding of the student perspectives with respect to the OWLS and specifically the student-perceived learning gains and their motivation within the course. The purpose of the focus groups will be to provide complementary data that will seek to clarify, elaborate, and enhance the findings from the first phase of the research⁵¹. Focus groups will be held at the end of the 2015 semesters from a random sample of 5 students in each of the university and community college courses. The focus groups will be led by an independent assessment consultant and analyzed for codes and tested for validity following the same procedures outlined above for the qualitative survey data. Taken as a whole, the qualitative

and quantitative data from both phases of this mixed methods model will result in a comprehensive assessment that ultimately leads to the best possible answers to the research questions in this study.

5.0 Community College Course Module

The module for the fall 2014 community college courses was developed to support the classroom goals by providing students with hands-on and virtual data collection, visualization, and analysis experiences. Specific learning objectives included problem solving strategies via Microsoft Excel software, hands-on data collection, hand calculations and unit conversions, basics of water quality monitoring, and water sustainability. The module was implemented into the course throughout a one week period near the end of the semester. Students participated in in-class and take home assignments using the OWLS and LEWAS data to understand and analyze water quantity, quality, and weather data. For example, students used the OWLS to view historical data that was simulated as if it was real time. This is illustrated in Figure 2, which shows a screenshot of the OWLS Single Graph View with volumetric flow and water temperature plotted against time. Students also used the OWLS to review a water main break case study that occurred at the LEWAS site and to visually investigate the watershed using geographic representations. Additionally, students visited a nearby river to collect their own water quality data.

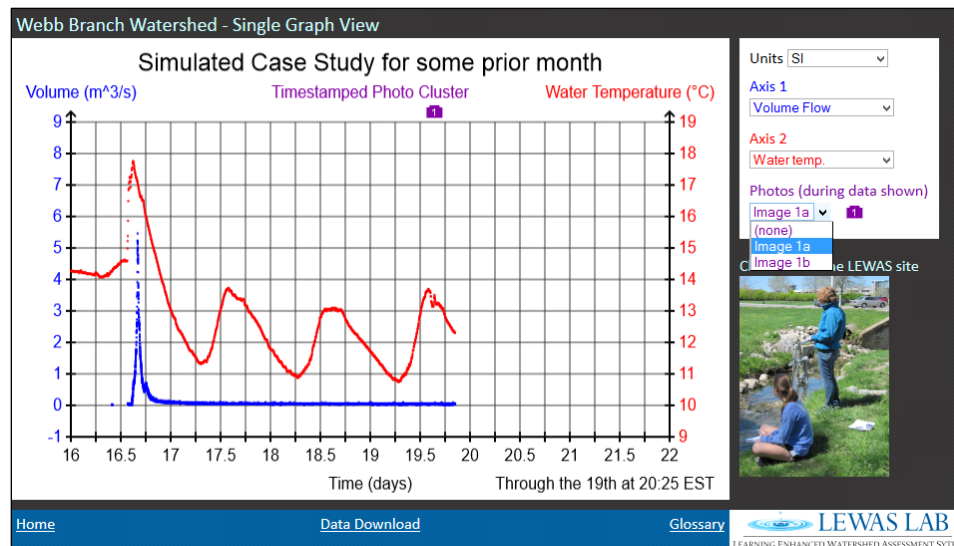


Figure 2. OWLS Screen Caption of Single Graph View

6.0 Results and Discussion

This focus of the results in this paper is on the pilot test in the fall 2014 community college course, which focused on student motivation and student perceived learning. Ongoing work in the spring 2015 semester is assessing student learning directly, as well as motivation and student perceived learning, as indicated in the methodology section, and while results from the

spring 2015 semester have not been collected and analyzed in time to include in this paper, they will be included in the associated presentation.

6.1 Hydrology Pilot Test (Spring 2014)

Comprehensive analysis of the results from students using the OWLS in the pilot test in the Hydrology course (n=30) can be found in Brogan et al.⁵⁴ This work assessed student perceptions only and did not directly assess student learning as will be done in the spring 2015 courses. However, the results from this test were positive with the majority of students indicating that the OWLS helped them to learn hydrology concepts and a significant majority (97%) indicating that they would recommend using OWLS in other courses. The results from this initial pilot test helped to inform the development of curricula and assessment for implementing the OWLS in the second pilot test in the community college course, which is the focus of the assessment in this paper.

6.2 VWCC Pilot Test (Fall 2014)

The results from the pilot study in the community college course (n = 27) indicated that students generally found the LEWAS and the OWLS to be useful in their course; however, many of the students felt that the modules were squeezed into an already busy class and wanted more time to complete the assignments. For example, when asked “If you were designing an introduction to engineering course, in what way(s), if any, would you incorporate a system similar to LEWAS into the course? Why?”, one student commented that it was “*a distraction from various other projects that are assigned*”, with another student commenting that it was “*first week of class material, so much to cover already.*” Still many students recommended implementing the LEWAS into future courses and introducing it earlier and more often throughout the semester.

Students also found the OWLS and real-time monitoring to be valuable in learning about man-made effects on water quality and quantity. For example, when asked “What value, if any, do you see in real-time monitoring of water quantity and quality?” one student responded, “*You can understand what is going on with real life phenomena*”, and another stated, “*The value of this ability is the real-world application that is has.*” Both of these students recognized that real-time data through the OWLS provided them with a connection from what they were learning in class to the real-world. It also fits within the first two levels of Blooms taxonomy, remembering (i.e., what is real-time monitoring, water quality, etc.) and understanding (i.e., how can this data be applied, analyzed, etc.).

Students were also asked to interpret how they would use the LEWAS in a different application based upon their understanding of the system. When asked “How can the LEWAS be used to educate the public about watershed health?” one student responded, “*It can help promote clean habits with the environment by actively showing the negative outcomes of the environment.*” Similarly, many other students indicated that the LEWAS data could be used in a way to not only educate the public but also enact change in the way that people interact with a

watershed. This demonstrated that the students were able to understand (level 2 Blooms: understanding) the value of environmental data and apply (level 3 Blooms: applying) that understanding to ways that they could educate the public.

The results from the MUSIC model reflect the motivation levels of the students within the community college course. Just as with the quantitative learning questions, because there was no control group, it is difficult to make any judgments as to how the OWLS modules affected student motivation within the course; however, by combining this information with the qualitative responses, there are still some takeaways that can be drawn from the assessment data. The students scored the highest on caring (5.4 on a scale of 1 to 6), indicating that they believed that the instructor cared whether or not they met the course objectives, and on success, indicating that they believed they could succeed if they put forth the necessary effort. Interestingly the students scored the lowest on understanding why the content is useful (4.6). While many students in the qualitative responses indicated that the module was useful to them, others felt that the module was squeezed into the course at the end and thus might not have been perceived as useful within the overall course. This indicates a divergence among student responses from the qualitative and quantitative data that will be further explored in the spring 2015 surveys and focus groups.

In addition to student assessments, the instructor of the community college course was asked interview questions to gain an instructor perspective on the effectiveness of the course implementation. When asked what the added benefits of using the system in his course, the instructor noted “*data, interesting data, and real-time high frequency data...data teaches you, (if) you can model it, you can understand your system.*” The instructor recognized the benefit of using real-time, real-world data in the classroom for the students. When asked what the difficulties were in implementing the modules in the course, the instructor reiterated what the student difficulties were and noted that “*In the way we teach it, it is just crammed into the end. So they don’t have time to appreciate it.*” Based on these comments, modules in the spring 2015 courses will be moved up to an earlier time and spread out over the course of the semester.

Overall, the assessments from the pilot tests indicate that a majority of students felt that the OWLS assignment was relevant to their coursework and found it valuable. In addition, the motivation assessment indicated that students scored the highest on motivation levels related to the care of the instructor and their abilities to succeed in the class. However, due to the limitations of the experimental design, the interpretation of the results should be taken into context considering the threats to internal validity. Even so, it still provides useful information that can be used to improve upon the OWLS modules and assessment procedures for the spring 2015 courses.

6.3 Hydrology and Community College (Spring 2015)

Results from the two pilot studies have helped to improve upon the development of curricula and assessment for the spring 2015 courses. Ongoing work in the spring 2015 semester

is testing student learning and motivation in graduate and undergraduate hydrology and freshman community college students. This will provide valuable information that directly tests the impact that real-time data and virtual lab experiences provided by the OWLS have on students in the classroom. This assessment will not be collected in time to include in this paper but will be included in the associated presentation.

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