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Development of a Crayfish Behavior Case Study for a New First-semester General Engineering Course Using a High-frequency Environmental Monitoring System

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Development of a Crayfish Behavior Case Study for a New First-Semester General Engineering Course Using a High Frequency Environmental Monitoring System

Abstract

In this work-in-progress paper, we present the development of an environmental case study for use in a first-year general engineering course. This development utilizes a real-time, high frequency environmental monitoring system located at an outlet of a watershed branch at a large land-grant university in the United States. This environmental monitoring system collects continuous water quality and quantity data and video footage and has been used as a platform for engineering education research and specific classroom interventions at different institutions in multiple countries within the last ten years, including projects integrated into engineering courses in which students were asked to evaluate different watershed events occurring at the system's site. Motivated by our previous experiences with cases and projects applied in engineering classes that allowed students to evaluate different site events, we focus on an event recorded in the system's database during which there was a significant increase in crayfish activity on the same day as an unidentified chemical event. In this paper, we present the development and planned implementation of a case study utilizing the environmental monitoring system to increase environmental awareness and to provide an authentic learning experience for problem solving for a new first-semester general engineering course in an engineering transfer program at a community college in the eastern United States. We first consider the benefits of using case studies for learning. We then provide an overview of the watershed monitoring system used to collect the data and some of the previous educational settings its data has been used in. Subsequently, we summarize the particular event used in this crayfish case study and the development of some of the data analysis products that will be provided to students. Finally, we discuss the planned implementation of this case study into the first-year general engineering course and its assessment and future steps to continue this research.

1. Introduction

Technological advances allow for the implementation of innovative learning activities in many fields, including environmental engineering. The current work-in-progress paper presents the development of one such environmental engineering learning activity based on an environmental case study that combines high-frequency water quantity and quality and weather data and co-located photo and video imagery from a watershed monitoring system, the Learning Enhancement Watershed Assessment System (LEWAS), located in a small urban watershed to investigate the short-term environmental impacts of a pollution event on the local crayfish population [1]- [4]. The use of this case study in a first-semester general engineering course increases students' exposure to environmental content and allows them to participate in an authentic learning activity that challenges them to consider possible relationships between the observed environmental data and crayfish movements that occurred during this event.

This implementation will occur in a new first-semester general engineering course that will be taught beginning in the fall 2021 semester. This course is part of an engineering transfer program at a community college in the eastern United States. This program provides the first two years of engineering courses for direct transfer as a junior into any bachelor's degree program in engineering at one of the public universities in the state. This required survey course, taught by one of the authors of this paper, introduces students to several topics including problem solving, information literacy, written and oral communication, teamwork, professionalism, ethics, the design process, significant figures, dimensional analysis, spreadsheet software, mathematical software scripts, descriptive statistics and technology applications within the field of engineering.

Within these topics, the current implementation will focus on facilitating learning activities that help students to solve problems by developing problem definitions, formulating hypotheses, stating their assumptions, identifying the knowns and unknowns, exploring resources, developing explanations, and communicating and reflecting on their proposed solutions in a team-based setting. Planned subsequent activities related to this implementation include students collecting their own environmental data via a simple software-controlled sensor application and analyzing this data using mathematical software scripts. Thus, this case study implementation and the planned subsequent activities provide an authentic learning experience that meets several of the stated learning outcomes of the course. Additionally, the two-year curriculum does not contain any environmental engineering courses, and the integration of this environmental engineering case study into the first-semester course exposes students to the field of environmental engineering.

2. Theoretical Framework: Case Studies

Case-based instruction has a long history of applications in different fields including engineering [5]. It has been categorized among different forms of student-centered instructional methods that create opportunities for active learning [6]. Raju and Sanker [7] defined a case study as "a record of a technical and business issue that actually has been faced by managers, together with surrounding facts, opinions, and prejudices upon which management decisions have to depend" [7, p. 502]. Such issues are often ill-structured and create connections with real world practices. Students will play an active role in their learning where they are able to take on more responsibility and construct their own versions of reality [6]. Within this context, authentic learning experiences make learning more relevant and engaging, and students will benefit from these experiences, as they close the gap between theoretical knowledge and practical application [8], [9]. Various studies emphasize the influence of case-based instruction on students' skills and abilities; Yadav et al. [8] provided an overview of such benefits including: using higher levels of Bloom's taxonomy, developing abilities to work on different contextual knowledge, facilitating the transfer and application to new contexts, and developing teamwork and critical thinking skills. While it appears that case-based instruction can be a very effective approach in teaching, developing and incorporating authentic cases is a challenging task. Additionally, evidence on the effectiveness of case-based instruction often relies on self-reported data by students and faculty [9], and there is less empirical evidence about how students actually learn using case studies [6], [10].

From a theoretical perspective, case-based instruction is supported by constructivist approaches to learning [6]. While constructivism includes different perspectives, the movement is inspired by the cognitive theory of learning, in particular works of Piaget [11]. According to cognitive theory, learning takes place as a result of changes in knowledge and understanding [12]. All versions of cognitive theory are concerned with learning as the process of creating mental models which are stored in one's long-term memory [13]. The notion of prior knowledge plays an important role in this framework. Students come to classrooms with their existing mental models including diverse perceptions, principles, and experiences. This existing knowledge is their foundation to create new knowledge [11]-[13]. In regard to the implications of cognitive perspectives of learning in practice, instruction and different learning activities should emphasize key features of concepts that are being learned, provide connection between new knowledge and students' prior knowledge, target deep processing of information and the structure of what is being learned, create opportunities for students' active engagement, and help students to develop metacognitive knowledge [13].

Constructivism, as a particular approach of the cognitive framework, highlights the role of learner. Learners construct their own mental models influenced by their experiences and interpretations, i.e. a learner is in charge of exploring his/her own understanding [13]. The learner is not a passive recipient of knowledge [11], and as a result of her interaction with the environment, she can develop a unique pattern of knowledge structure. According to this perspective, interactions with people and the environment are a crucial factor that can be translated into active learning practices. In addition, in line with constructivism, metacognition can improve problem solving [11], [14] and the ability to transfer information to a new context [6], [14]. Both can flourish using case-based instruction. Furthermore, implementation of real-world scenarios, in addition to metacognition or self-regulation, leads to deep and meaningful learning [15].

As explained in the Introduction, we will implement a case study on observed crayfish behavior in a first-year engineering course. In line with constructivist approaches to learning, we aim to cultivate a learning environment in which students play an active role in learning. Through working with other students in teams, engaging with meaningful activities during the class, reflecting on their learning experiences, and critically evaluating both their own and others' knowledge and understanding in the process of learning, we anticipate that students will benefit from this unique and authentic learning experience by fulfilling the project objectives listed in the Case Study Development section.

3. System Structure and Previous Educational Initiatives

System Structure

As mentioned in the Introduction, the LEWAS is a real-time, high-frequency environmental monitoring system for a small, urban watershed. The system is located on Webb Branch of Stroubles Creek on Virginia Tech's campus and has been developed and maintained by a group of students and faculty representing several engineering disciplines, environmental science, chemistry and industrial design . The functions of this system include measuring water quality and quantity, and weather data from the watershed and providing the users with measured data in real-time in the form of a web-based interface. Owing to its functionality, the system comprises hardware and software components that enable it to complete the designated tasks (Figure 1). The hardware infrastructure consists of components that interact directly with the watershed, and other components that are used for storing and transferring the data from the watershed to the users. The users can access the data through a data sharing infrastructure developed by the lab, which is a web-based application. The hardware components of the system that interact directly with the watershed includes an Acoustic Doppler Current Profiler (ADCP) flow meter that measures stage and velocity; a water quality sonde that measures pH, dissolved oxygen, oxygen reduction potential, turbidity, specific conductivity, and temperature; a weather data transmitter that measures precipitation, wind speed and direction, temperature, pressure, and humidity; and a video camera to record real-time pictures and video of the stream conditions at the measurement site. These data components are collected and processed using a Raspberry Pi system, which is a low cost, open source and programming language flexible computer. The Pi is connected to a router that enables it to communicate to the system's server where the data is stored in the system's database.

The power supply for the entire system follows a hybrid structure which is due to its two different sources of power. Two solar panels are installed at the site location with hardware that regulates the power to 24 V and charges two 12 V deep-cycle lead acid batteries connected in series to act as the primary source of power. The other source of power is through grid power that was added as a backup source to improve the reliability of the power supply so that no instruments lose power during extended overcast periods [16].

Similarly, the software infrastructure comprises components that interact with the sensors to get the data, and the components that facilitate the flow of data between different nodes of the network. Based on their roles, the software components have been developed in different languages, such as, Python, C++, JavaScript, HTML, CSS, SQL and JSON. Since the system records and handles high volume of data, APIs have been developed to regulate the number of requests to the system to avoid overburdening the system. These APIs were developed in GoLang. The software components conduct the flow of information between different hardware components.

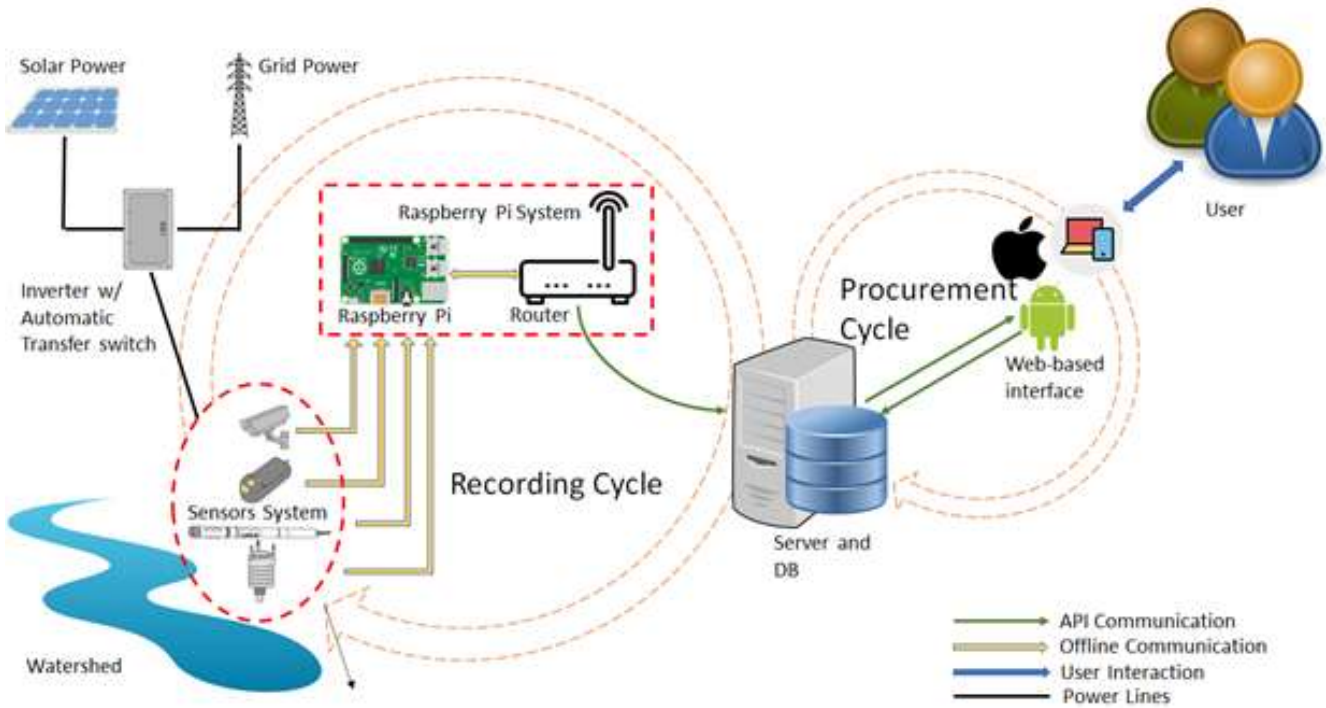

Figure 1. Graphical representation of the LEWAS

Data Flow

The flow of data originates from the sensors that communicate the data through offline scripts and feed it to the Raspberry Pi system which consists of the Raspberry Pi and the router. Together, they act as a single unit that receives the information from the sensors and transfers it to the server where it is stored in the database. The flow of information from sensors to the server forms the *Recording Cycle* of the network and the flow of data is unidirectional. This process is repeated continuously as new measurements are made.

The second part of the flow is called the *Procurement Cycle* which is a bidirectional flow cycle. The flow originates when data is requested by the user through the web-based interface application. This request is received by the server, which posts the data on the application. The flow of information between the web application and the server is facilitated by APIs. As denoted in Figure 1, flow of information from the Raspberry Pi to the server, and between the server and the application is conducted over the internet.

Previous Course Implementations

The LEWAS is being integrated into the undergraduate curriculum to enhance teaching and learning practices. This has been done through experiential learning initiatives that seek to increase student learning and motivation by engaging students in active and cooperative learning while supporting classroom goals. Since this real-time environmental monitoring system started in 2008 it has been utilized in various undergraduate courses at several community colleges and universities across three continents, via diverse learning initiatives [17]- [20].Some of these classroom implementations involved analyzing a simulated real-time case study using historical data and imagery In a recent intervention, students were asked to evaluate the flooding potential at this site and characterize the quality of the stream habitat at the site based on water quality parameters with regard to road salt, fish health, and invertebrate health. The proposed crayfish case study discussed in this paper is a novel project that will be implemented in a course for the first time in the fall of 2021.

4. Case Study Development

This section highlights the information that will be presented to students in a first-year general engineering course at a community college in the eastern United States. It begins with a general description of the relevant information pertaining to the case study and the applicable environmental and crayfish data. Subsequently, the environmental relevance and educational significance are discussed. Finally, this section highlights what will be expected of the students that will be given this case study.

Background for the Case Study

On September 20, 2016, there was an unidentified chemical event which drastically affected the water quality at the base of the LEWAS site, pictured in Figure 1. This system was utilized to gather live water quality data from the water quality sonde and video footage from a video camera. Anecdotal evidence based on five years of student visits to the lab site, prior to 2016, suggest that crayfish are rarely visible when the stream environment is not being disturbed. However, following changes in water quality on the afternoon of September 20, 2016, large numbers of crayfish moved rapidly downstream and several crawled onto the banks, as seen in Figure 2.

Figure 2. Image of crayfish observed on the banks on September 20, 2016

One of the authors of this paper investigated this case of abnormal crayfish behavior. In her investigation she explored possible environmental conditions and corresponding water quality parameters that may have disturbed the crayfish at the lab site. All water quality parameters collected by the sonde were investigated as possible influences on crayfish behavior. Using MATLAB, water temperature, pH, dissolved oxygen and specific conductivity were graphed along with cumulative rainfall and stage over several days around this event in the month of September, 2016, in search of abnormalities (Figure 3). This figure shows that temperature and dissolved oxygen values undergo daily temperature variations. Decreases in pH (toward 7) and specific conductivity (toward 0) on the nineteenth that take more than 12 hours to return to base levels are typical of rainfall events. Other drastic increases in pH and specific conductivity on the seventeenth, nineteenth, twentieth and twenty first correspond to unidentified chemical events.

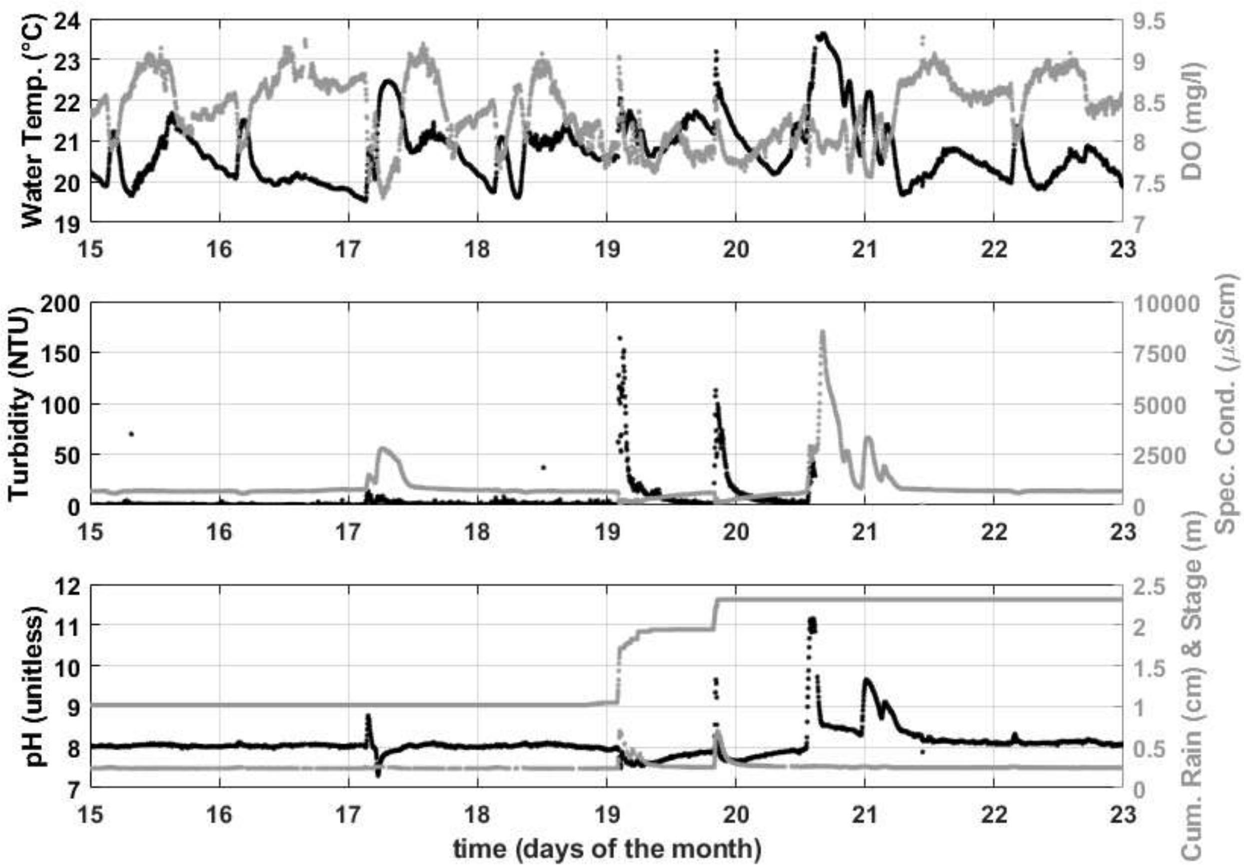

Figure 3. Water quality changes over time in September 2016

Additionally, video tracking analysis was conducted to assess patterns in crayfish movement and establish the crayfish behavior as abnormal. Video tracking is not an ideal method for monitoring crayfish movements for various reasons. The most obvious reason is a lack of visibility. Seeing crayfish in the water requires low turbidity, excellent lighting and no solar reflections from the water's surface. Another limitation is that, in typical conditions, crayfish spend most of their time hidden under rocks. Additionally, the camera resolution is often not high enough to distinguish types of crayfish, which must be done by collecting samples. Despite these limitations, video data provides the advantage of collecting continuous data over long periods of time with minimal effort and is an excellent way of collecting data that can show general movement trends during current or past events.

Due to the sun angle at this time of year, the tracking could only be accomplished during certain times of day. Crayfish movements were tracked and analyzed for several days before, during and after the chemical event. The method of tracking the crayfish behavior consisted of several steps. The first step involved breaking the videos from the site into frames, which were stored at 48 frames per minute of real-time data. Next, the pixel location of each crayfish observed in each frame were recorded as x and y coordinates. Each set of x and y position pairs represents a different crayfish present on the screen at the same time. Subsequently, the crayfish location data was imported into a MATLAB program that creates a graph which connects the dots of each crayfish's location, displaying each unique path over a given time period (Figure 4). In the graphs pictured in Figure 4, the white portion of the screen represents the area of the creek visible in the frame of the video camera. The water was very turbid during the event, blocking the view of the crayfish in the deeper portion of the creek, and reflection from the water surface blocked part of the view in the morning. The video tracking analysis was extremely involved and time consuming. Thus the students will not be asked to conduct their own tracking. However, the results from the previously executed analysis will be provided to the students for reference.

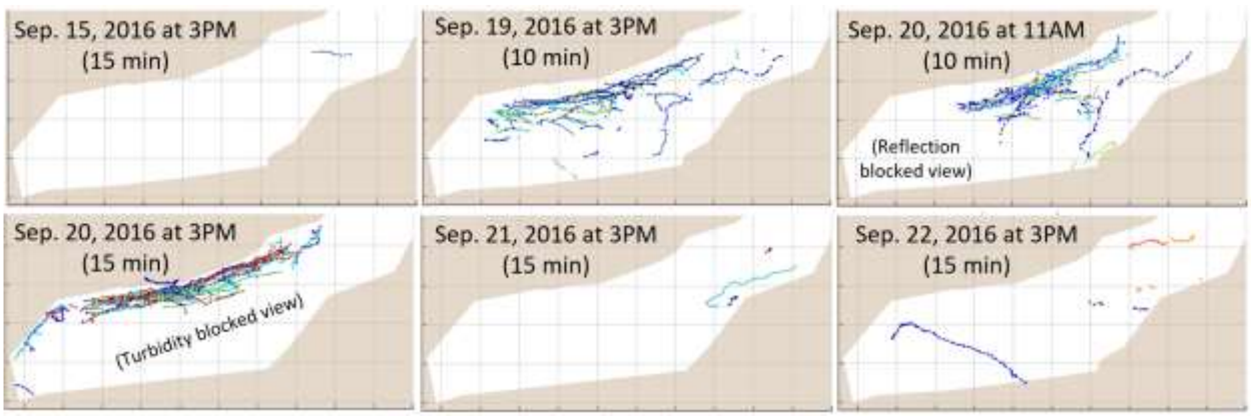

Figure 4. Sample of results from Video Tracking analysis over 10 or 15 minute time periods before, during and after the chemical events (video data not available on September 16-18)

Overall, the possible explanations for the abnormal crayfish behavior that were found were all correlational but causality could not be established. Students will be expected to conduct a similar analysis to answer the questions highlighted in the Project Objectives section below. The results from this author's research will not be revealed further here to avoid biasing the findings of the future engineering students' authentic learning experience when this case study is brought to the classroom.

Environmental Significance

The Webb Branch watershed picks up a lot of sediment and runoff as it flows through campus and the adjacent town, undergoing frequent changes in water quality. Contaminants, runoff and sediment enter the watershed through a myriad of known and unknown sources at many places along the stream. These additions to the water can cause drastic changes in water quality, which in turn, can drastically affect the ecosystem as a whole.

The observed changes in crayfish behavior sparked the interest of the lab members, but why focus on crayfish? Crayfish play a vital role in the ecosystems they are a part of and are considered to be good bioindicators of water quality [21]. Crayfish are major energy transformers between various trophic levels in an ecosystem [22]. They are key predators in the benthic zone and interact with the whole sub-web of species there, thus contributing to the overall stability of the aquatic environment [23]. Detritus and benthic algae are both very important sources of energy. When crayfish consume these energy-rich plants, it allows the energy to flow more freely throughout the environment, which is an important aid in making energy from benthic production available to fish [23]. Beyond this, crayfish serve as bioindicators of water quality, meaning their status can be used to analyze an ecosystem's health [24]. Crayfish often exhibit observable changes in behavior, size and strength based on the long-term values of water quality parameters in the body of water they inhabit. For example, in water with low pH, calcium uptake is slowed and crayfish exoskeletons are weaker [25]. Additionally, crayfish are sensitive to pollution and other environmental stressors, thus the absence of native crayfish species can indicate poor stream health [24].

Project Objectives

By the completion of this case study, students will be able to:

- Perform basic data analysis using large datasets
- Demonstrate ability to use MATLAB in analyzing data and presenting the results
- Function effectively on a team
- Communicate effectively through written and oral presentation

After being given the background information and relevant data, students will be asked to explore and identify potential causes of observed changes in crayfish behavior. In exploration of potential causes of crayfish behavior, the students will be working through many of the course objectives for the new first-year general engineering course outlined in Section 5. This case study provides students with context for problem solving, literature review, data analysis, communication, and environmental awareness.

5. Course Integration

The proposed implementation of this case study in the classroom environment involves students being provided with a general case description and the raw environmental data to analyze in Excel and/or MATLAB. Additionally, students will be provided results of video tracking analysis to draw their own conclusions from. In this case study there is no established right or wrong answer, and students will be urged to explore and explain the unknown. Working in teams, they will then be asked to state their assumptions and formulate hypotheses about relationships between their graphed data and the video tracking results, complete some literature review, write a report, and give an oral presentation about their process of inquiry and findings.

The following are course outcomes for the new first-year general engineering course offered that will be fulfilled through the implementation of this case study:

- “Identify and solve problems using engineering methodologies”
- “Find, evaluate, and effectively use technical information, including scholarly literature”
- “Use spreadsheet, word processing and presentation software to collect, organize, analyze and present engineering data”
- “Find, evaluate, and effectively use technical information, including scholarly literature”
- “Form, plan, and complete team-based engineering work”
- “Use systematic methods to create a proper engineering solution including formulation, representation, assumptions, questioning, communication, and evaluation”

Implementation has been planned to include three to four class periods of 50 minutes each. During the first dedicated session, which will take place during the first few weeks of the semester, students will be introduced to the case study and the structure of the LEWAS. As part of the activities, students will work in teams to begin developing a clear understanding of the problem—team formation and discussion of team development and effective strategies for team work will be completed in week 3. In the second session, students will investigate a particular water quality dataset as a real-world example of working with data, leading into an individual homework assignment, so that students will each gain practice in data analysis using MATLAB/Excel. Following the data analysis portion, discussion of information literacy skills and library resources will be executed in which the instructor will check in with each team on their status of exploration of relevant resources and provide guidance as needed. In the next class period, students will brainstorm for hypothesis development. Throughout the sessions, the instructor will deliberately pose questions, provide students with time to think and reflect on different tasks within teams, and facilitate discussion and create a dialogue environment within the classroom.

Several assignments will be incorporated throughout the semester to assess various intended outcomes and to help students progress to their final reports and presentations and answer the major question under investigation: what are the potential causes of observed changes in crayfish behavior? The intended activities are as follows:

- Case definition and reflection I (individual)
- Data analysis and graphing (individual)
- Identification and analysis of possible explanations (team)
- Case definition and reflection II (team-based)
- Discussing potential explanation and justify the explanation (team)
- Final report (team)
- Final presentation (team)
- Peer evaluation (individual-based)

In the world of professional engineering, engineers are often asked questions that have no clear answer. We anticipate that implementation of this case-based instruction will provide students with an authentic and meaningful learning experience. We believe the proposed activity can foster a learning environment that increases students’ ability to develop and assess alternative ways to investigate a given ambiguous situation and accompanying data set, which will be an essential asset in real-world practice.

6. Assessment

The intervention described in this paper will take advantage of several benefits of case-based instruction. Students will be provided with an opportunity for meaningful application of water quality data, interpretation of real-world data, and creating a visual representation of data using MATLAB/Excel. In addition, the discussion format used in the class provides opportunities for students to work on relevant and beneficial activities, including experiencing a novel team-based activity, and fostering teamwork and collaboration skills. Furthermore, it provides students with an opportunity to practice higher-level thinking in tandem with analyzing, reflecting, and justifying potential causes for abnormal crayfish behavior. Importantly, the case does not involve a clear solution. Through navigation through such an ambiguous situation, we posit that students will take an active role in the process of learning and in envisioning different possibilities through engagement with their peers. Along with the educational tasks stated above, we plan to incorporate a Likert-scale survey to evaluate students’ perceptions of their engagement to provide us with a more robust picture of the influence of this intervention. In addition, our research will focus on incorporating individual reflective journals at several points during the semester and open-ended questions at the end of semester to explore students’ critical thinking process. The questions will be designed to understand whether students’ reflections on their thought processes, including rational and imaginary components, represent changes in metacognitive awareness.

7. Conclusion and Next Steps

The case study discussed in this paper provides a novel, ill-structured environmental event that allows students to investigate complex data and engage in different activities, such as brainstorming, reviewing literature, developing hypotheses, evaluating hypotheses, working with data, creating visual evidence using MATLAB/Excel and making informed decisions. The deliberate incorporation of cases helps students to question different assumptions, evaluate different alternatives and reason. Broadly speaking, this will influence students’ critical thinking.

The next steps are finalizing the write-up of the case that will be given to students and deliberately planning for different learning activities, including methods of in-class discussion, students’ in-class activities, reflection prompts, and assessment tools to explore students’ progress and their understanding of the problem. Meanwhile our research will focus on assessing students' critical thinking skills.

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