THE EFFECTIVENESS OF A HANDS-ON DESKTOP MODULE FOR LEARNING OPEN CHANNEL FLOW CONCEPTS

By

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ABSTRACT

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The overarching goal of this study was focused on identifying the effectiveness of a physical model (named the Desktop Learning Module – DLM) implemented in an undergraduate engineering class and identifying what concepts of open channel flow showed improvement utilizing the DLM. There were three goals within the project: 1) to make a successful, scaled DLM that was small enough to fit on a desk, while showing fundamentals of open channel flow; 2) to improve students' conceptual understanding of the fundamental concepts; and 3) to identify misconceptions and contribute new information to the field of engineering education and conceptual understanding. During spring 2011, 50 open-ended undergraduate interviews were completed with three goals: 1) to write pre/post-tests for comparison between a control and experimental group to identify the effectiveness of the DLM; 2) to obtain detailed data on students understanding of open channel flow concepts; and 3) to develop worksheets to accompany the DLM interactive sessions. Results suggest students have misconceptions relating to the hydraulic and energy grade line (HGL/EGL), flow transitions, and flow profiles. Interviews with a large percentage of tested students exposed false beliefs relating to transitions.

For example, more than 50 percent of tested students drew a decrease in water depth for a subcritical drop, rather than an increase in depth. To assess the effectiveness of the DLM, pre and post-tests were given to a control and an experimental group. The control group received traditional lecture covering open channel flow; the experimental group received two 50-minute interactive sessions with the DLM and accompanying worksheets. Qualitative and Quantitative data were collected and analyzed for improvement in not only the score on the tests, but in the justification of participant answers. Both sets of data provide evidence that the DLM is nearly 2.5 times more effective when taking the difference between the pre- and post-test scores than traditional lecture.

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CHAPTER ONE

INTRODUCTION

Many studies have been conducted to find whether interactive learning is more effective in teaching fundamental concepts of the STEM fields than a traditional lecture method (Brown & Poor, 2010; Chi, 2009). Similar, this study identifies the effectiveness of a physical model appropriately named the Desktop Learning Module (DLM) when implemented in an undergraduate water resources engineering course at a public university. There were three major goals of the project: 1) to make a successful, scaled DLM that was small enough to fit on a desk while demonstrating fundamentals of open channel flow; 2) to improve students' conceptual understanding of the fundamental concepts; and 3) to identify misconceptions and contribute new information to the field of engineering education and conceptual understanding.

After implementing 50 open-ended interviews, common misunderstandings were found relating to open channel flow concepts. Using these data, different obstructions were made and used with the DLM to demonstrate specific concepts of open channel flow. Also, to compare two groups, a control and experimental, pre- and post-tests were developed from the interview data to measure the difference in conceptual understanding before and after the two different instruction methods. Quantitative data were obtained through assigning a score between 0 and 10 to each individual pre- and post-test. Qualitative data were collected through requiring participants justify their answer on the pre- and post-tests. Through implementing this cohort research design, which follows two groups, one receiving traditional treatment while the other receives the intervention, all goals outlined above were achieved and detailed throughout chapters two and three with a summary of conclusions in chapter four.

Chapter two provides commentary regarding the effectiveness of the Desktop Learning Module. Beginning with the methodology of the study, this chapter progresses to identify what open channel flow concepts had the most and least impact from implementing the DLM. Results include a standard statistical paired t-test that provides strong evidence that the DLM is effective over a range of open channel flow concepts. Qualitative data collected through participant justification also provided strong evidence of the DLM's effectiveness. Many experimental participants justified their answer in a greater level of detail when compared to the control participants. Together, these types of data provide a strong case indicating the effectiveness of the DLM.

Chapter three is a brief discussion of common misconceptions found within the research study. Although many incorrect processes were found over all tested concepts of open channel flow, only a selection of the results is reported for brevity. In specific, results of a broad crested weir channel profile are reported in detail. Along with identifying common misconceptions, commentary is provided contributing to the field of engineering conceptual understanding and relating this contribution to the findings. The chapter provides direct student quotes that demonstrate incorrect answers of a broad crested weir profile. These quotes are representative of three different cognitive processes: sequential language; a two variable system; and process with initiation. All cognitive processes suggest students are analyzing a system sequentially or linearly rather than looking at a control volume at an instantaneous point of time. Finally, chapter four is a summary of conclusions that link chapters two and three in relation to the effectiveness of the DLM.

This was a collaborative project between many people and as a result, the research assistant did not write all of the sections detailed in the following chapters; the following is work that is recognized by others on the project. Dr. Olusola Adesope provided many statistical contributions to chapter two to demonstrate the differences between the two groups. Dr. Shane Brown and Dr. Devlin Montfort wrote portions of chapter three that were published for the Frontiers in Education Conference, held in Seattle, Washington in October of 2012 under the title of *Open Channel Flow Misconceptions and Ontological Categories.* Chapters two and three were primarily written by the research assistant, but went through many drafts between the community members. The research assistant performed all of the research work, beginning with identifying a research plan, implementing and analyzing any interviews, pre- and post-tests, development of the DLM and Worksheets. However, Alicia Flatt, an undergraduate aided in developing the accompanying worksheets and Cory Tobin helped develop the initial DLM prototype.

CHAPTER TWO

THE EFFECTIVENESS OF THE DESKTOP LEARNING MODULE

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ABSTRACT

The overarching goal of this study focused on identifying the effectiveness of a physical model termed the Desktop Learning Module, or DLM implemented in an undergraduate engineering class and identifying what concepts of open channel flow showed improvement utilizing the DLM. There were two goals within the project: 1) make a successful, scaled DLM that was small enough to fit on a desk, while showing fundamentals of open channel flow and 2) improve students' conceptual understanding of the fundamental concepts. 50 open-ended undergraduate interviews were completed with three goals: 1) to write pre/post-tests for comparison between a control and experimental group to identify the effectiveness of the DLM; 2) obtain detailed data on students understanding of open channel flow concepts; and 3) develop worksheets to accompany the DLM interactive sessions. Results suggest students have misconceptions relating to the hydraulic and energy grade line (HGL/EGL), flow transitions, and flow profiles. A large percentage of tested students revealed false beliefs relating to transitions. For example, more than 50 percent of tested students drew a decrease in water depth for a subcritical drop, rather than an increase in depth. To assess the effectiveness of the DLM, pre and post-tests were given to a control and experimental group. The control group received traditional lecture over open channel flow; the experimental group received two 50-minute interactive sessions with the DLM and accompanying worksheets. Qualitative and Quantitative data were collected and analyzed for improvement in not only the score of the tests, but the justification of participant answers. Both sets of data provide evidence that the DLM is nearly 2.5 times more effective than traditional lecture. Even further, as a participant's score increased, so did the detail of justification on the post-test answer.

KEYWORDS: Conceptual change, active, hands-on learning, concept quizzes, miniature desktop learning modules

1. Introduction

Students often have to grasp major engineering topics while attempting to understand the fundamentals of an engineering topic in a short amount of time. As students are subjected to more engineering concepts in less time, important concepts are missed and more importantly, misunderstood; this leads to misconceptions. More specifically, misconceptions relating to key fundamental open channel concepts are developed and then carried with a student throughout their collegiate and sometimes professional careers. Many studies in engineering education have been used to assess the benefits of implementing an active (Conner & Goff 2001), researched-based curriculum compared to traditional lecture (Prince 2004). The majority of these studies indicate that an active curriculum and interaction between students and conceptual material is more beneficial in understanding fundamental concepts of engineering.

Historically, research has shown that students have conceptual difficulty with fundamental engineering concepts (Streveler et al. 2008, Steif et al., 2010) and can primarily perform only elementary calculations rather than understanding the basic phenomena governing a system. Interaction between the learner and a physical model developed at Washington State University allows the learner to directly observe the effects of manipulating different parameters of open channel flow such as channel slope, flow rate, as well as a variety of flow obstructions. Ideally, this method of instruction will help students surmount conceptual difficulties and achieve a higher understanding of the governing principles in open channel flow.

A comparative case study was performed to observe the effects of implementing an interactive learning technique in an undergraduate course over fundamental open channel flow concepts. Rather than the traditional class atmosphere, participants in this study worked with an interactive physical model that replicates fundamental concepts of open channel flow and worksheets that included group and individual work. Through implementing the physical model, three types of effective interventions were utilized to correct students' conceptual understanding.

The first intervention applied was hands-on learning, which promotes the direct manipulation of a system (Abdul et al. 2011, Conner & Goff 2001). The second was interactive learning, which promotes group work to achieve a depth in understanding beyond that which could be accomplished by any one individual (Chi, 2009). Finally, the third was formative assessment, which allows for immediate feedback from teammates, teaching assistants (TAs) and the instructor with no penalties to the student for incorrect answers (Nicol & Macfarlane-Dick, 2006). Together, these three interventions help correct common conceptual difficulties and improve student conceptual understanding of fundamental open channel flow concepts.

By 'conceptual understanding' we refer to the kind of knowledge that students use when explaining or predicting phenomena (Vosniadou 1994). Conceptual understanding research is largely based on the finding that students often develop the ability to use equations and perform calculations without understanding what they mean, or being able to apply them to new contexts (Vosniadou 1994, Cary 2000, Duit & Treagust 2003). The ability to deal with new problems during professional practice using a fundamental understanding of analyses is vital to the practice of engineering, which makes the development and identification of conceptual understanding imperative to engineering education (Donovan, M. S. et al. 1999).

Evaluation of conceptual improvement is often in the form of asking participants if they think they have improved rather than attempting to measure that improvement. Such self-reported measures are fraught with subjectivity and may be susceptible to social desirability biases, thereby limiting the validity of conclusions that can be drawn from them (Bowman, 2011). The research design implemented in this study was used to measure the increase (or decrease) of conceptual understanding and features the following three aspects: 1) collected data include qualitative (analyzing student written explanations for cognitive processes) and quantitative findings (score analysis) that provide more than one perspective on the effectiveness of the physical model; 2) in-depth data analysis at a level of requiring specific justifications from students for the answers given, which furthers the perspective of students' conceptual change; 3) assessment techniques that were tailored for this study by developing all curriculum specifically to accompany the physical model. Also, we developed a unique rubric to measure conceptual competency of a students' answer on the pre- and post-test assessments.

Research Goal

The purpose of this study was to evaluate the effectiveness of the physical model and associated worksheets on improving students' conceptual understanding. Through implementing a comparative evaluation design between two course offerings and pre- and post-tests assessments, t-test and effect size analysis were performed to understand quantitative results while participant justifications (written and spoken) were evaluated to comprehend qualitative findings. Using a mixed methods research design approach provides multiple perspectives that can contribute to identifying students' conceptual change.

2. The Desktop Learning Module and Associated Curricula

2.1 The Desktop Learning Module

The physical model that we developed is termed the Desktop Learning Module (DLM) because of its intended use in the classroom, rather than in a laboratory, by small groups of students. For this study, we developed and applied a DLM for hydraulic flow, which, at its most basic level, conveys fluid and measures flow. The DLM includes a reservoir, pump, and flow meter, and can be used with open channels (i.e., flumes) or closed conduits. In the flume configuration shown in Fig. 1, piping goes from the exit of the pump to the entrance of the flume. Water exits the flume directly into the reservoir. Dimensions of the DLM base unit are approximately 40.5 cm left to right, 23 cm from top to bottom, and 28 cm front to back. The flume attachment is approximately 76 cm left to right, 23 cm top to bottom, and 2.5 cm in width and graduation marks are etched into the flume subdivided into mm tick marks and labeled at 1 cm intervals. Finally, a sluice gate is typically inserted into the tall portion of the flume (to the right in Figure 1) to build up static head when heeded.

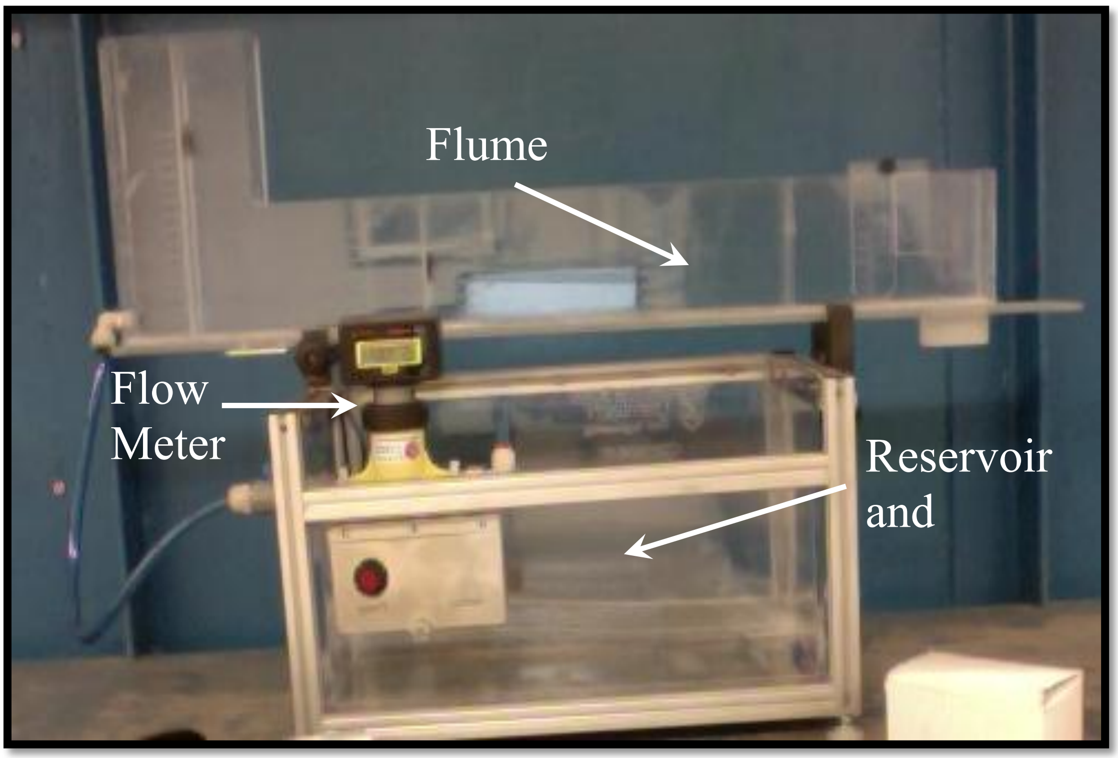


Fig 1. A visual representation of the Desktop Learning Module

The flume conveys water from right to left and allows for different flow obstructions, such as a broad crested weir, to be placed inside, while a digital level and flow meter allows students to report the slope of the flume and flow rate, respectively. The base unit includes a storage area in front of the reservoir. There is also a battery-housing unit that is mounted above ground level to prevent short-circuiting in case of a spill.

Fundamental phenomena occurring in natural and engineered open channel flow settings can be demonstrated using the DLM by placing different obstructions in the flume and by varying the slope and flow rate. We designed the flume with a variety of features that allow the study of a number of open channel flow concepts. These features include the following: the ability to insert a broad and sharp crested weir; vary flow rate; vary the channel slope; and provide channel transitions in elevation, e.g., drops in channel elevation over a short period of distance. This collective set of features helps students investigate specific fundamental concepts that are difficult to understand, such as subcritical, supercritical, and critical flow or the relationships between flow rate, flow regime, depth, and channel slope.

2.2 Development of Accompanying Curricula

Interviews were conducted with 50 students on a variety of open channel flow concepts during spring semester 2011. The course of interest was Water Resources Engineering at Washington State University and was composed of primarily junior and level standing students. Data collected from the interviews were used to confirm common conceptual difficulties and develop associated worksheets with the DLM implementation, and to develop pre- and post-test assessments, discussed in the methodology section. This was done through performing qualitative data analysis (a process defined in detail in the methodology) and grouping individual participant explanations to find which were the most prominent. The concepts associated with the most prominent conceptual misunderstandings were chosen as the focus for the worksheets and the pre- and post-tests. For example, when participants were asked to explain how depth would change for a supercritical drop transition, an abrupt drop in the channel bottom for fast-moving water that results in a decrease in flow depth, over 60% of the interviewed participants answered incorrectly and could not provide detailed explanations. Therefore, we decided to include transitions on the worksheets and pre- and post-tests.

Utilizing results from the interviews related to flow profiles, hydraulic jumps, flow transitions, and the hydraulic and energy grade lines (HGL and EGL, respectively) we developed exercises to include in two worksheets to be used over the period of two classroom-implementation sessions. One worksheet details hydraulic jumps and flow profiles while the other features transitions and HGL/EGL. Each worksheet has four sections, as detailed in Table 1) in the following order: 1) Learning Objectives; 2) Conceptual Pre-Activity; 3) DLM Activity; and 4) Reflection. Sections (1) and (2) were to be completed before the DLM interaction session; sections (3) and (4) were to be completed during the sessions.

Table 1. A summary of what each worksheet included.

Concept	Learning Objectives	Conceptual Pre-Activity	DLM Activity	Reflection
Flow Transitions[1]	Identify energy and depth change through different flow regimes	Draw four different profiles and relate changes in depth to specific energy	Model a supercritical drop and determine flow regimes	Explain why an understanding of flow transitions is important
HGL/EGL[1]	Understand placement of HGL/EGL	-	Calculate and draw both grade lines	-
Flow Profiles[2]	Draw flow profiles for multiple channel configurations	Draw four different flow profiles and explain if a hydraulic jump can occur	Label different flow regimes for three different profiles	Label different flow regimes for real world situations
Hydraulic Jumps[2]	Explain why hydraulic jumps occur and relate to specific energy curve	Describe and explain hydraulic jumps in own words	Create three hydraulic jump profiles and calculate related specific energy	Identify hydraulic jumps in real world situations

[1]denotes concepts addressed by the first worksheet; [2]denotes concepts addressed by the second worksheet

The worksheets were tested with three separate focus groups that took place over the period of two months before the DLM implementation. Modifications were made to each worksheet based on the feedback from the focus groups to improve the worksheets. During each focus group, three student volunteers that had taken water resources previously, worked through the worksheets and made detailed notes as to what was difficult to understand or problem areas in each of the worksheets. One example of a change made as a result of a focus group was providing directions on each page in part (3) of the worksheets. This way, participants wouldn't have to always page flip to read what they had to accomplish for each question.

2.3 Effective Interventions with the DLM

The implementation of the DLM and worksheets is founded on three well-known and thoroughly researched educational implementations that have been shown to improve student learning across a variety of contexts: hands-on learning, interactive learning environment and formative assessment. Each are discussed below.

The DLM sessions achieved hands-on learning, which is defined as physical manipulation of a system or experiment (Abdul et al. 2011, Conner & Goff 2001), by examining the combined effects of varying flow rate and slope, and configuring up to eight different profile configurations. The term Interactive Learning Environment (ILE) is defined as working in a group to (either physically or verbally) achieve one common task (Chi, 2009; Salomon & Perkins, 1998). Chi uses the example of two students interacting primarily verbally (with little physical interaction) when they coordinate their use of a mouse at a single computer monitor. This particular example relates to the DLM in the sense that students are primarily interacting verbally rather than physically, working to finish the worksheets while observing the effects demonstrated through the DLM. However, to achieve the full definition of ILE, the worksheets were developed such that all students were required to be engaged, e.g. by requiring that each student take a turn in setting up a new hydraulic jump and interacting physically with the physical system. There were a total of 12 groups of three in both sessions, allowing the groups to verbally interact as well. Implementing groups of three rather than groups of two or four allows for an optimal number of students per DLM and departmental resources. If groups of two were implemented there was the risk of the two participants not being able to work through the worksheets. If groups of four were utilized then there was the chance that not all participants would have an opportunity to interact with the DLM.

Rather than focusing on grades, formative assessment involves using feedback from students and teachers followed by additional instruction to improve student learning and to guide the learners thinking to a clearer understanding of fundamental underlying concepts that govern phenomenon (Nicol & Macfarlane-Dick, 2006). The DLM activity was used to introduce formative assessment by first asking the students questions about a concept or a process (in which the students may be incorrect in answering), and second to allow them to visualize the process, the results of which may be inconsistent with what the students thought they would observe. This provides immediate visual and sensory feedback, which causes them to reconsider their original premises and rethink their understanding of the underlying concept or process. The worksheets were not graded, but given a score for participation (i.e., the participants were assigned points based on their level of effort). For example, when participants were asked to draw two different grade lines (HGL and EGL) directly on the flume, they were required to try it themselves first and then receive feedback (if incorrect) from a teacher or teaching assistant.

3. Methodology

This study explored the effectiveness the DLM and associated curriculum in terms of changing students' understanding of fundamental open channel flow concepts using a pre- and post-test comparative case study design. Participants in the comparative case study were chosen from two course offerings of an undergraduate engineering course focused on water resources engineering at a public university. A conceptual assessment instrument was developed using data from 50 student interviews on open-channel flow concepts. Improvement was identified through assigning numerical scores to the pre- and post-tests as well as qualitative analysis of students' written justifications of their answers. Details about the methodology are given in the following subsections.

3.1 Participant Selection

A total of 149 students, in three groups, participated in this study: the interview group, a control group, and an experimental group. All students were drawn from three course offerings of Water Resources Engineering, a required junior level engineering course focused on open channel and closed conduit water flow, pumps and pump systems, estimation of components of the hydrologic cycle, and surface water runoff. Two different professors instructed the three different course offerings (shown in Table 2). Professor 1 is the PI on this project while Professor 2 has taught the course many times and offered to be part of this study. Table 2 below provides complete details on the numbers of participants in each group and the time in which they took part in the study.

Table 2. Summary of overall schedule and Participant and Professor information

Participant Group / Purpose	Professor	Number of Participants	School Term
Interview / Develop conceptual assessment	1	50 (94%)[2]	Spring 2011
Control / Implement common teaching practices	2	41 (87%)	Fall 2011
Experimental / Implement DLM	1	58 (86%)	Spring 2012

[2] percentage of total class population that participated in the study.

There were a total of 24 groups of three participating in the experimental group during the DLM interactive sessions. While 12 groups were completing one DLM interactive session, the other 12 groups received lecture over Hydrology from the professors' PhD student. Once the first group finished both DLM sessions, the groups switched and the first group received the Hydrology lectures while the second group completed the DLM sessions. Through Implementing groups of three rather than groups of two or four allows for an optimal number of students per

DLM and departmental resources. If groups of two were implemented there was the risk of the two participants not being able to work through the worksheets. If groups of four were utilized then there was the chance that not all participants would have an opportunity to interact with the DLM.

Participants from the interview group were given the option not to participant when they arrived for the interviews, and also had the option to not have their data included in the study. As a result, slightly less than 100% of the students participated as seen in Table 2. The control and experimental participants were given the same option and only paired data were used for analysis of gains (e.g. matching pre- and post-tests). Also, a few students whose pre-post test data was available opted out of the study.

3.2 Internal Validity

Internal validity in educational evaluation is achieved when a causal relation between the implementation of the DLM and the gains on pre- post-tests is established (Gliner et. al, 2009, p. 101). To isolate the effects of the DLM and associated worksheets on student learning, the implementations of the control and experimental courses were made as similar as possible; although two different instructors taught these courses, the base coverage of all open channel material was kept similar. By base coverage, we mean the teaching style, lecture notes, examples, in-class activities, homework assignments, and examinations were kept as similar as possible. Each group received the same number of 50-minute lecture periods (11) covering open channel flow, however the experimental group had two 50-minute DLM sessions and nine 50-minute lecture periods. The only major difference was the implementation of the DLM in the experimental course. Table 3 describes the way each key concept was covered for the control coverage and DLM coverage. It should also be noted that the control case received active learning, however it was a different kind of active learning. They received in-class activities where participants worked with peers to complete an example problem. This promotes discussion, however the discussion between peers did not include the entire class as many participants worked on their own or asked a question to the peer tutors and/or instructor.

Table 3. A summary of the DLM Coverage pertaining to each key concept in a worksheet.

Key Concept	DLM Session Coverage
Flow Profiles	- Placed a sluice gate and broad crested weir into the flume while observing the effects on the water profile
Flow Transitions	- Placed a supercritical drop transition and observed the effects
Hydraulic and Energy Grade Lines	- Drew the HGL and EGL on the flume using transparencies
Hydraulic Jumps	- Placed various weirs in the flume while manipulating the channel slope to produce hydraulic jumps

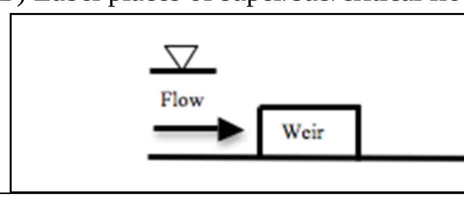
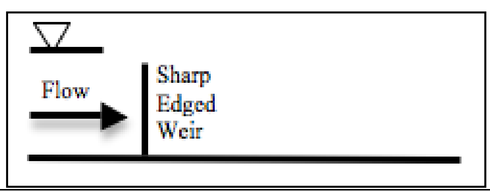
All participants had completed the prerequisite fluid mechanics course before enrolling in water resources engineering, and therefore had similar educational background knowledge in open channel flow concepts. Additionally, the pre-test scores were compared and no statistically-significant differences were found between the two groups. The average pre-test scores for the control and experimental group are 14 ± 5.6 % and 10 ± 4.7 %, respectively. It should be noted that for analysis purposes, the pre-test scores were adjusted so that each group were quantitatively equal before assessment. The adjusted means are reported in the results section.

3.3 Assessment Development and Implementation

Two assessments were developed in the following order: open-ended interviews, and pre- and post-test assessments. The following section provides detail about how each assessment was developed and how they were used to measure conceptual understanding.

The interview conceptual assessment was developed initially through meeting with a civil engineering faculty member who had taught water resources engineering and fluid mechanics to determine, historically, which open channel flow concepts students have had difficulty learning. After an initial draft was completed, the assessment was further developed through focus groups with two civil engineering faculty. Changes to the interview content included the following: order of concept questions, level of probing questions to ask, inclusion of all the fundamentals of open channel flow, and level of detail on each picture relating to each question. A brief summary in Table 4 shows the key questions asked during the interviews and specific concepts on which participants were tested.

Table 4. Summary of concepts covered during the interviews.

Concept	Questions Asked
Open Channel Flow HGL/EGL	A) Draw the HGL and EGL from points A to B. B) How would you determine how much water flows from A to B? C) Write the Energy Equation between A and B.
Specific Energy	A) How does water transition between A and B? B) How does the specific energy change between points A and B?
Flow Profiles	A) Draw the flow profiles for A – D[4]. B) Label places of super/sub/critical flow 
Hydraulic Jumps	A) Draw the flow profiles for A – D. B) Label places where a hydraulic jump occurs. C) What do you think a hydraulic jump is? 

[3] Point A was upstream on the diagram; point B was downstream
[4] A – D represents four flow profiles with different channel configurations

Each interview was audio recorded and professionally transcribed. The transcriptions were imported into the qualitative data software NVivo (2010) and each student interview packet, which included a representative figure (quarter-page) and a written response, was scanned and synced to their respective transcription. Explanations given by each student were coded for each question to identify areas of conceptual difficulty. Grouping each student answer (by incorrect versus correct answers) identified a hierarchical list of concepts that were difficult for students to learn and explain. The hierarchical list was used to do the initial development of the associated worksheets, and to develop the pre- and post-tests

Following an initial draft of the pre- and post-tests utilizing the interview data, the assessment was further developed through focus groups with four engineering faculty and validated and revised through the student interviews. During the span of approximately eight focus groups, changes were made to the pre- and post-tests that include the following: wording of question prompts, question diagrams, how much time should be given to the participants, and when to implement the pre- and post-tests. Questions were developed through building on the open-ended approach taken in ranking tasks (Brown and Poor, 2010) and concept inventories (Mitchell, Martin and Newell, 2001).

The final pre- and post-assessments consisted of seven qualitative questions (with figures) covering the following concepts: flow transitions, flow profiles, EGL/HGL, hydraulic jumps and channel roughness. Questions were open-ended and requested that students predict or explain fundamental phenomena. Students were given a total of 15 minutes to complete the purely qualitative, seven-question test. Following the schedule of the course (pressurized pipe flow, open channel flow, and hydrology in that order), each group was given the pre-test one lecture period after the pressurized pipe flow unit; the post-test was given one lecture period after the open channel unit.

3.4 Quantitative Assessment Scoring

Development of the assessment rubric to assign scores to each pre- and post-test paralleled the steps outlined in *Scoring Rubrics in the Classroom: Using Performance Criteria for Assessing* *and Improving Performance* (Arter and McTighe 2001). The six steps are outlined briefly from chapter three, as follows. Step 1: Gather samples of student performance. Step 2: Sort student work into groups and write down justifications for each point assignment. Step 3: Cluster reasons into traits or important dimensions of performance. Step 4: Write a value-neutral definition of each trait. Step 5: Find samples of student performance that illustrate each score point on each trait. Step 6: Continually refine. Table 5 shows the details of our final generalized rubric, which was used to assign a value of 0-10 for each question on the pre- and post-tests

Table 5. Generalized rubric for assigned scoring.

0 points	1 point (Low)	3	5 points (Medium)	7	9 points (High)
No Answer	Correct with no explanation	Explanation is strongly flawed	Explanation is related to fundamentals	Explanation relates to fundamentals strongly	Provides clear explanation
OR	OR	OR	OR	OR	OR
No Reasoning	Correct/Incorrect w/incorrect logic	50-75% critical mistakes/incorrect	25-50% critical mikes/Incorrect	25% critical mistake/Incorrect	1 simple mistake

The reliability of the rubric and score assignment was established by having an undergraduate student assign scores to ten pre- and post-tests, which were selected as the lower, middle, and upper total score assignment from the scores assigned by the researchers. Following the score assignment of the undergraduate student, each score assignment on each test was compared to the researchers' initial score. If there was a marginally large (greater than 20%) difference in the score assignment, brief discussions were held to resolve the differences until agreement within 20% was achieved. Not more than 15% of the scores were marginally different between the research assistant and undergraduate.

Once the pre- and post-test scores were adjusted one time, an engineering faculty (who is familiar with the concepts taught in the course based on their teaching experience) scored the same ten pre- and post-tests graded by the undergraduate. The same process was used for comparison and any marginal differences were addressed and corrected. Finally, the research assistant re-scored for a third time the remaining 188 pre- and post-tests for consistency. Results from the score assignment were used for statistical data detailed below and in the results section.

Standard statistical techniques were implemented to analyze the multiple-score dataset. A standard ‘gains’ (G) formula was used (Equation 1 below) to normalize the increase or decrease between each participant’s pre- and post-test score. The number ten in the denominator represents how many points were possible for each pre- and post-test question. A standard paired t-test was performed, as well as a test for significance to determine if the quantitative gains were statistically significant to the point where they support the effectiveness of the DLM implementation. The p-values for each question are given in the results section.

$$G = (Post – Pre)/(10 - Pre) \quad (1)$$

3.6 Qualitative Assessment

Students’ written justifications of their answers on the pre- and post-tests were analyzed utilizing the qualitative data analysis tool, NVivio (2010) and separating the data into codes and nodes. A code is a piece of data that holds information of interest; a node is a group of similar codes. To prevent inconsistencies, a single researcher performed all of the coding. In this process student responses were labeled as correct or incorrect responses. Similar correct or incorrect responses were then grouped and coded for specific words of interest. Finally, a node was created based on common words of interest. The following is one example of what similar responses entail. Participant 1 response: “Depth increases because the change in channel elevation relates to a positive elevation change, therefore y increases”; participant 2 response “depth increases from one and two because the change in elevation gives head to specific energy.” Both participant quotes essentially described a similar justification so were grouped together to form a node.

3.7 Implementation and Schedule

The effort put forward to implement the DLM without sacrificing a lot of classroom instruction was not difficult to accomplish. The class size at time of implementation was 72 students and one professor taught the course. Utilizing 15 Desktop Learning Modules, the class was broken into two sections of 36 students each. While one section of 36 students was in the DLM sessions, the other section received two lectures from the Professor's PhD student over hydrology. Once the first half of the students finished the two 50-minute DLM sessions, they received the same two lectures over hydrology while the second section of 36 students had the two DLM sessions. During the DLM sessions, three teaching assistants assisted the professor in answering questions and mobilizing the DLM's to a laboratory room that had tables and chairs for the students.

3.8 Limitations and Weaknesses

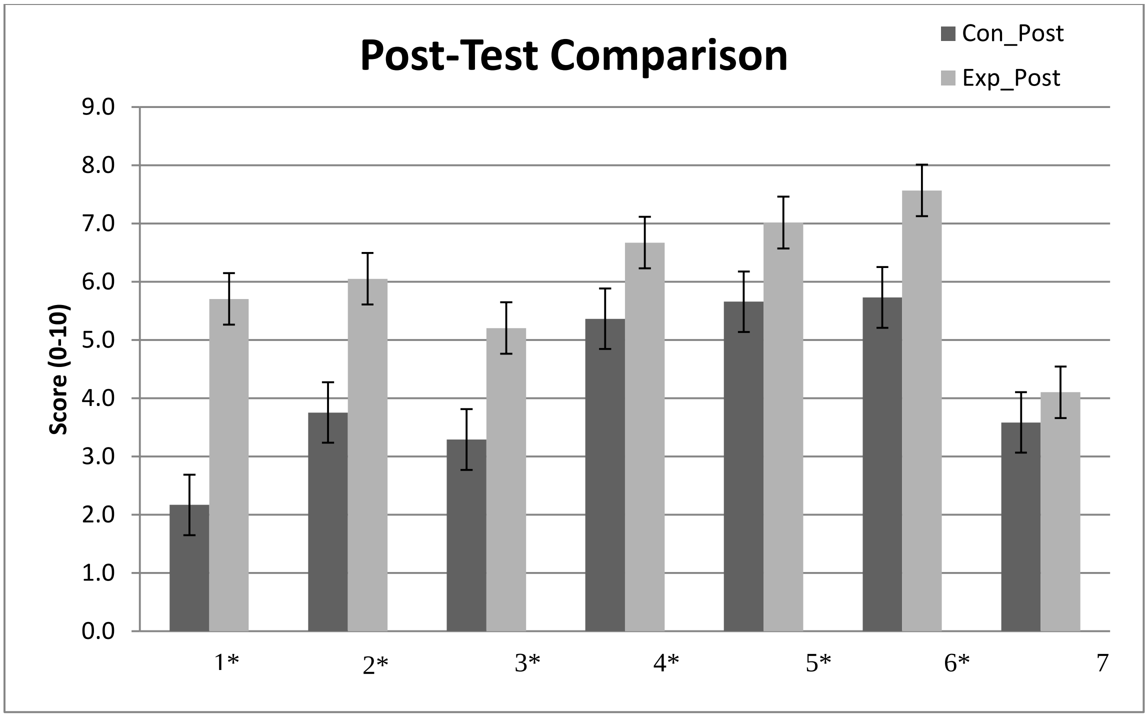
Te fact that two different professors were used to teach the control and experimental groups is one point of weakness. Although a series of meetings were held before implementation of the research plan to ensure the teaching style, homework, exams, etc. were kept as similar as possible, it is very difficult to have two exactly same professors. Also, not all background data could be collected of each individual participant. This includes: demographical and detailed course background information, if Water Resources Engineering was the participants' major, and whether the participant worked better in a morning or afternoon course. Finally, the GPA of each participant could not be obtained for comparison between the two groups. Each of these points of weaknesses or limitations could contribute to some variability in the results as discussed later.

4. RESULTS

4.1. Global Statistical Analysis and Findings

The experimental group indicated higher average point score between their pre- and post-tests than the control group for every question. A summary graph shown in Fig. 2 below illustrates the average points per question and associated standard deviation bars. Also, Table 6 provides details on the statistical analysis of each question; i.e. a comparison between the control and experimental group was performed to obtain adjusted means, standard deviation, t-test values, p-values, and effect size (to measure the strength between the two groups in the statistical population) for each question (control commentary is provided later). This summary table provides the statistical evidence that the DLM is effective. Questions one through six all had a p-value close to 0. The p-value for the control question (7) demonstrates the similarity between groups as it is greater than 0.05 representing statistically-insignificant improvement for this question. Further, the effect size is small and provides evidence that there were no significant differences between the two groups. This is significant because the effect size represents the strength between two variables (in this case the experimental and control group). The average effect size for the six experimental questions (one through six in Figure 2 below) is 0.98. This means that that the average participant in the experimental group would score higher than 84% of the participants in the control group (Coe, 2002, p.4). Whereas the effect size for the control question (number seven) is 0.12 indicates that 54% of the participants in the experimental group would score higher than the participants in the control group.

Fig. 2. Differences between the control and experimental points for each question.



* denotes significant differences between groups (p-value less than 0.05)

Table 6. Summary of statistical data that represents improvement in the experimental group

Question	Group	Adj. Means	Std. Dev.	T-Statistic	P-Value	Effect Size
1	Control	1.8	2.2	5.6	~ 0.00	1.38
	Experimental	5.9	3.5			
2	Control	3.6	2.7	3.8	~0.00	0.77
	Experimental	6.1	3.6			
3	Control	2.9	2.6	4.1	~ 0.00	1.06
	Experimental	5.5	2.1			
4	Control	5.0	1.8	5.4	~ 0.00	1.04
	Experimental	6.9	1.8			
5	Control	5.4	2.1	3.9	~ 0.00	0.81
	Experimental	7.2	2.1			
6	Control	5.5	2.9	3.0	~ 0.00	0.85
	Experimental	7.7	2.1			
7 (Control)	Control	3.7	2.6	1.6	0.114	0.12
	Experimental	4.1	2.5			

The following section contains more detail on three questions from the pre- and post-tests. These questions were chosen to include an example from each of the three main concepts covered in the pre- and post-test assessments, as well as to minimize the interpretation or previous knowledge of open channel flow processes required of the readers. Each section shows one representative question and a brief description of the correct answer. A summary table provides the conceptual details of improvement pertaining to each question. Finally, representative student written explanations are included in each section to demonstrate the difference in justification of answers between the control and experimental groups and to provide evidence that students' cognitive processes transition to a more critical technique of analysis.

4.2 Flow Transitions – A Subcritical Drop
Question prompt: How does depth change between points one and two in Fig. 3 below?

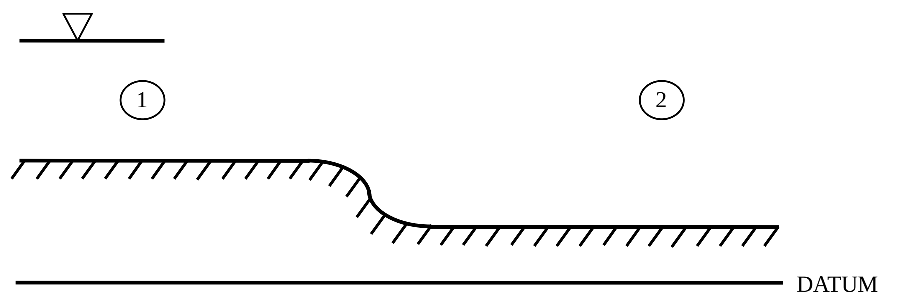


Fig. 3. The visual prompt provided to students to support questions about flow transitions. The written prompt described the flow regime as subcritical, and noted that the triangle marked the water surface while the hatched line indicated the channel bottom.

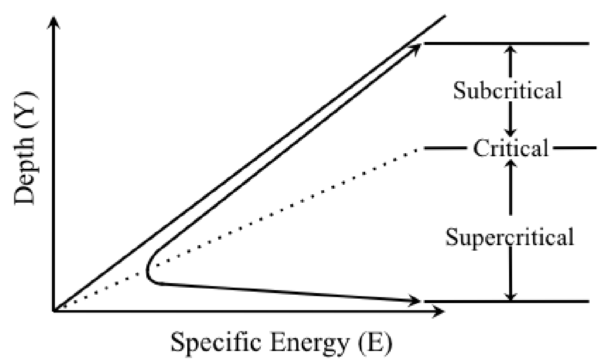


Fig. 4. The Specific Energy Curve. A Relationship Between Flow Regimes, Flow Depth, and Specific Energy.

To answer this question correctly, the participants would need to utilize the specific energy curve (Fig. 4) and the specific energy equation (Equation 2 below), in relation to two points on the flow profile. Because Figure 3 shows an abrupt drop in the channel bottom under subcritical flow, the decrease in channel bottom corresponds to an increase in specific energy at point (2) using Equation 2 below. Participants had to use the specific energy curve to see that an increase in specific energy correlates to an increase in depth. Therefore, depth increases.

$$E_2 = E_1 + \Delta Z \tag{2}$$

Participants spent most of one DLM session (about 35 minutes) placing a supercritical drop transition in the flume and working through the associated worksheet. They were asked to perform calculations to identify the flow regime (supercritical or subcritical) and to describe the change in depth observed due to the drop transition. Students in the control group received one lecture period, one example problem during lecture, and one homework problem related to the transitions concept.

The majority of participants who answered this incorrectly did so because they attempted to answer it using the concept of velocity. They argued that velocity increases as the slope increases, which led them to assume that the depth decreases as required by the conservation of mass. This is incorrect for a number of reasons, the most important of which being that velocity is determined primarily by channel roughness in addition to channel slope and geometry. After one session with the DLM, the experimental group was better able to correctly answer this question (9 pre-tests correct to 40 post-tests correct), and they were also less likely to reason using velocity. A total of 18 students referenced velocity in the pre-test, while only five referenced it in the post-tests. The control did not show a similar change in reasoning, with approximately the same number of students' referencing velocity in the pre- and post-test. A brief summary of Question 1 answers and student quotes can be reviewed in Table 7 below.

Table 7. A Summary of Question 1 Control and Experimental Common Answers and Quotes.

Question 1 Summary	Control Post-Test	Experimental Post-Test
Proportion of Correct Answers	5/41	40/60
Most Common Answer	21 participants emphasized changes in velocity, and	25 participants referred to changes in specific energy

	incorrectly assumed that increased velocity causes decreased depth.	and the flow regime (subcritical flow).
Representative Participant Written Explanation	"Depth decreases since velocity increases because going downhill, it speeds up."	"Depth increases due to ΔZ increasing and if starting in subcritical flow, this causes an increase in depth. $E_2 = E_1 + \Delta Z$."

4.3. The Hydraulic and Energy Grade Line (HGL/EGL)

Question prompt: Draw the HGL and EGL for the channel profile shown in Fig 5.

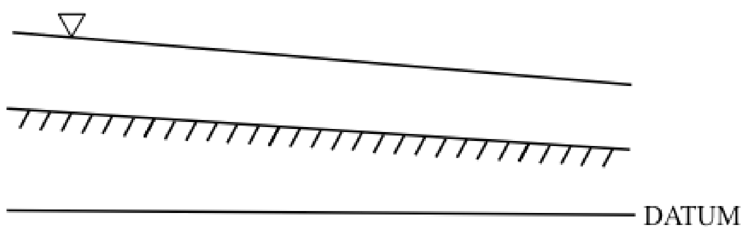


Fig. 5. The visual prompt provided to students to support the question about the hydraulic and energy grade lines. The written prompt described the channel geometry and slope as constant, and noted that the triangle marked the water surface while the hatched line indicated the channel bottom.

For participants to answer this question correctly they would need to know the difference between the HGL and EGL) and what specific terms and types of energy were associated with each grade line. The HGL includes the elevation head and depth; the EGL includes the elevation head, depth, and velocity head. A correct answer would show the HGL along the water's surface (because the elevation plus the depth is exactly equal to the water's surface elevation) with the EGL parallel and a distance of $V^2/2g$ (the energy due to velocity, expressed in head) above the HGL.

Participants interacted with the DLM and the HGL/EGL concept by drawing the grade lines on the flume using transparencies, i.e., by drawing HGL at the water surface and EGL a distance of $V^2/2g$ above the water surface. Once each group had collectively finished drawing the grade lines on the flume, an assistant checked their work, which developed into informal instruction if the students had made mistakes or had questions. The control group received a brief lecture (approximately 10 minutes) over the HGL and EGL. They had no homework on the concept, and only saw a diagram during lecture.

The majority of participants who answered this incorrectly did so because they mixed the terms relating to the HGL and EGL. Some indicated that the EGL was above the HGL and both were above the water surface as the HGL includes elevation and velocity head. Fundamentally, this means that the participants who answered with this reasoning did not understand that the pressure for an open channel flow system is water depth (Y) when the reference point is the channel bottom. After one part of one DLM session, the experimental group was better able to correctly answer this question (9 correct to 44 correct), and they were less likely to confuse the important components of each. Twenty-three experimental group participants confused the HGL and EGL in the pre-test, while only one did so in the post-test. The control group did not show a similar change in reasoning and actually showed an increase in number of participants indicating this incorrect profile on the post-test from one to seven. This is particularly interesting because the distinction between the HGL and EGL is one of definition, which would not normally be expected to improve through hands-on activities. A brief summary of Question 3 answers and representative participant written quotes can be viewed in Table 8 below.

Table 8. A Summary of Question 3 Control and Experimental Common Answers.

Question 4 Summary	Control Post-Test	Experimental Post-Test
Portion of Correct Answers	10/41	44/58
Most Common	Seven participants indicated the	32 participants had reasoning

Answer	EGL is above the HGL but both are above the water surface. There were a total of nine different incorrect answers.	through correctly placing the HGL and EGL. They also provided the correct terms (Z, Y, $V^2/2g$) to each grade line. Some mentioned depth is pressure for an open channel.
Representative Participant Written Explanation	'The EGL includes pressure, velocity and elevation. The HGL includes just the elevation and velocity.' Note: Answers were variable in justification.	'Neglecting headloss, the EGL is above the HGL by $V^2/2g$ and has the same slope as the bed. In open channel flow, the HGL corresponds to the water surface because there is no pressure.' (Note: student referenced water surface as datum)

4.4 Flow Profiles – Supercritical, Subcritical, and Critical Flow

Question prompt: Draw the most accurate representation of the flow profile. Label where subcritical, supercritical, and critical flow is, and explain your reasoning.

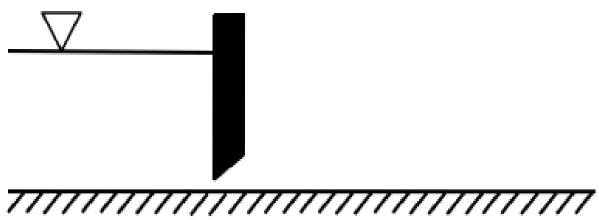


Fig. 6. The visual prompt provided to students to support questions about flow profiles. The written prompt described the flow regime as subcritical and noted that the triangle marked the water surface while the hatched line indicated the channel bottom.

For participants to answer correctly they would have to notice the visual queue of the gap between the channel bottom and the point of the gate. The gap is small enough to assume flow passes through Y_c (critical depth), which is instantaneous. They would also have to indicate that flow begins in subcritical (deep and slower) and is forced to supercritical (shallow and fast) after flowing underneath the sluice gate. The flow will transition from subcritical to supercritical (through a hydraulic jump) if the bottom of the gate is less than Y_c. Fundamentally, the flow regime is transitioning based on the specific energy curve (Fig. 4) starting on the upper part of the graph in subcritical flow and ending on the lower part of the graph in supercritical flow. A visual representation of the correct answer can be seen below in Fig. 7.

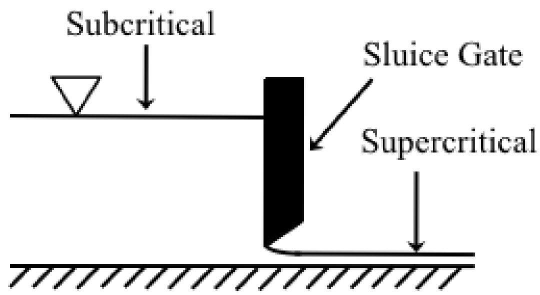


Fig. 7. Correct flow profile and placement of the subcritical, supercritical, and critical flow regions; triangle indicates water surface.

Participants made this flow profile in the DLM using various sizes of gates; they also varied the flow rate, and slope of the flume to observe the resulting effects. In addition, there was not one case where the water surface spilt over the top of the weir; all variations went underneath the sluice gate. Participants in the experimental group were prompted to draw the profile they observed in the flume, label the different flow regimes, label the depth before each flow regime (i.e. y_1, y_c, and y_2), and report their values of flow rate and slope. Participants in the control group saw a drawing of a sluice gate (similar to Figure 9), watched videos of various flow profiles, and were asked conceptual questions such as ‘where are the places of supercritical, subcritical, and critical flow for this profile’ during lecture

The majority of participants in the control group indicated the correct flow profile for this question but used incorrect fundamentals. Rather than relating their answer to “the depth under the gate is less than Y_c” or “the fluid is being forced under”, they used the relationship Q = VA. Although Q = VA is technically correct, it cannot be used to answer the all questions about flow depth because it is not enough information to solve all possible problems; the further information of specific energy is required. The written prompt indicated the fluid begins in subcritical flow and is at steady state, uniform conditions. Therefore the fluid is forced under the gate passing through critical flow into a supercritical flow regime. After one DLM session, the experimental group was better able to correctly answer this question (19 correct to 50 correct), and they were less likely to use the relationship Q = VA for their justification. Overall 20 participants referenced one of these two situations in the pre-test, while zero referenced it in the post-test. A brief summary of this question answers and representative participant written quotes can be viewed in Table 9 below

Table 9. A Summary of Question 7 Control and Experimental Common Answers.

Question 7 Summary	Control Post-Test	Experimental Post-Test
Portion of Correct Answers	24/41	48/58
Most Common Answer	The majority of participants indicated the correct flow profile but justified their answer with Q = VA. Only 9 mentioned any reference to flow regime.	24 provided a description stating the sluice gate 'forced' the water supercritical or 'less than Y_c'
Representative Participant Written Explanation	'Y [depth] must change, and will flow at the same Q [flow rate] which means V [velocity] increases [so depth decreases]'	'When fluid goes under the weir, it is forces to supercritical flow for some amount of time'

4.5 Channel Roughness – Control Question

A question about how channel roughness affects open channel flow processes, (see Figure 10), was included in the pre- and post-tests as a control because the DLM sessions did not address this concept. Although it is possible to change the DLM's roughness, the experimental participants were not asked any questions about roughness during the DLM sessions and received the same instruction over the concept as the control participants. Participants were asked to explain how the roughness of the channel would affect water depth, beginning in supercritical flow.

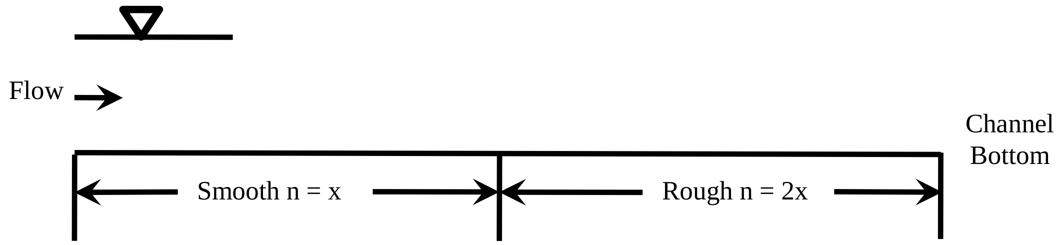


Fig. 8. The visual prompt provided to students to support questions about channel roughness. The written prompt described the flow regime as supercritical and noted that the rough portion is twice as rough as the smooth portion. Participants were queued to use Manning's Equation with the inclusion of 'n'.

For participants to answer this question correctly, they would need to utilize the flow rate equation known as Manning's Equation (Equation 3) or the relationship Q=VA. Ideally, through noticing that Manning's Number 'n' doubled between the two sections in Figure 10, the flow rate (Q) would decrease as 'n' is in the denominator in Equation 3 and all other variables were stated as constant in the problem description. To maintain steady-state conditions (which was stated in the problem description) the area would increase and velocity would decrease utilizing the relationship Q = VA. Therefore, depth increases over the rough section labeled as 'Rough n = 2x' in Fig. 10.

$$Q=(K_n/n)\, R^{2/3}\, So^{1/2}\, A \qquad (3)$$

Where
- Q = Flow Rate
- K_n = Conversion Factor
- n = Mannings Coefficient
- $R^{2/3}$ = Hydraulic Radius
- $So^{1/2}$ = Channel Slope
- A = Cross Sectional Area

The few participants who answered this question incorrectly (~25%) did so because they attempted to answer it using the concepts of roughness and velocity (which are ok concepts to utilize, just miss-applied for this situation) and indicated a decrease in water depth. They argued that roughness decreases velocity so when there is twice as much roughness the velocity decreases even further causing a decrease in water depth. This is technically backwards (as in some participants drew a decrease in water depth and used these concepts for their rationalization). The conceptual justification is “novice at best” and does not include the level of detail expected from junior level collegiate students to meet course objectives and requirements. Most students answered this question correctly using Q = VA or Manning’s Equation as their justification. Table 10 summarizes the qualitative data and Table 11 below summarizes the statistical data. Note that the most common answer is the same for both groups unlike the other qualitative summary tables where the most common answers were incorrect for the control group and correct for the experimental group.

Table 10. Representative Participant Quotes for the Control Question.

Question 7 Summary	Control Post-Test	Experimental Post-Test
Proportion of Correct Answers	28/41	46/58
Most Common Answer	The majority of correct responses (19) indicated the roughness slowed down the velocity and using the relationship Q=VA, concluded that the water depth increased.	Again, 33 participants whom answered correctly mentioned the concepts of roughness and velocity to rationalize their answer.
Representative Participant Written Explanation	‘Roughness will cause more friction, which leads to a slower velocity. Thus increasing the depth of the water.’	‘The roughness will decrease velocity and therefore create a deeper depth.’

The amount of participants that answered this question using the relationship Q = VA or Manning’s Equation on the post-tests is nearly the same between the control and experimental groups, i.e., 56% of participants in the control group were correct on the pre-test and 68% were correct on the post-test); an increase of 12%. The experimental group showed an increase in the number of correct answers going from 51.7% to 79.2%. These percentages indicate that the group responses for both groups are more statistically and qualitatively similar for the control question than any other question in the study. This evidence suggests that, without a DLM session relating to the concept of channel roughness, conceptual difficulties of this concept will not significantly change over time like it has for other concepts.

5. Discussion and Conclusion

All pieces of data (quantitative and qualitative) provide strong evidence that the DLM was effective for the selected open channel concepts. The technique in which the DLM was implemented had a strong impact on this conceptual improvement, as the time provided for the DLM interaction was weighted toward allowing students to run quick experiments related to different concepts rather than detailed calculations for the whole session. Through applying the two 'experimental' sessions, students had a chance to have one-on-one interactions with an instructor or teaching assistant and time to address any questions they may have had pertaining to open channel flow.

It is clear that the experimental group performed better on the post-test and showed a greater gain from the pre- to the post-test than the control group. This evidence suggests that direct interaction with the DLM and accompanying worksheets are significant enough to cause an increase in the understanding of fundamental open channel flow concepts. When comparing the difference of the pre- and post-tests gains, the average increase between groups was 17.1%, which is an increase of 17.5 points. Furthermore, the average pre-score of the experimental group was 9.5 points out of 70 and the average post-score was 43 points out of 70. In other words, the experimental group went from a failing score in the pre-test to a satisfactory score in the post-test; whereas the control participants remained at a failing score for the post-test.

Combining the results from two different areas (conceptual explanations and assigning numerical scores to each set of tests) provides a strong case that the DLM is effective. Students in the experimental group not only provided the correct answer more often, but also changed their own reasoning more often than students in the control group. The statistically significant improvement between the control and experimental group indicates that the experimental section of the course was more effective, as the two courses were comparable in every aspect except for the inclusion of the DLM in the experimental group. Additionally, a control question on channel roughness, which was not addressed in the DLM sessions, did not show a statistically significant improvement between the experimental and control group (shown in Table 11). Taken together, these sources of evidence indicate that the DLM sessions were effective in improving student understanding.

These improvements were from only 100 minutes (an 18.2% change of class time activities) of interactive instruction, and taking the average difference in gains between the two groups, increased students understanding by an average of 300%. Although the control and experimental groups were allocated the same amount of time to cover open channel flow concepts, the structure of the allotted time differs. The control group received purely lecture sessions where as the experimental group received lecture and DLM sessions. It is important to note that although the experimental group had both types of instruction methods, the amount of time spent on each individual concept (i.e. hydraulic jumps, specific energy, etc) was 15-25 minutes during the DLM sessions. This is approximately the same amount of time allocated for each concept between the control and experimental group, just instructed using a different method.

Through introducing an active learning environment for students to interact one-on-one with an instructor and the exploratory DLM device, significant conceptual gains were seen for nearly all participants. However, there were a small portion of students who demonstrated a decrease in conceptual understanding, but this could be attributed to other factors such as student motivation or self-efficacy, which is beyond the scope of this article. This active method benefitted nearly all students on a fundamental basis and helped correct any misconceptions students may have held before proper instruction.

The fact that the DLM sessions were composed of three interactive components, the worksheets, the DLM, and active discussions with the group, and between groups and the faculty member or TA, gives rise to the question 'is improvement only based on the DLM, only the worksheets, only the increased active discussion, or a combination or all three?' This cannot be determined from the nature of the study, but the improvement can likely be attributed to the combination of all three components as they complimented each other. For example, the worksheets prompted students to perform certain experiments with the DLM and record observations. Discussions between individuals within the group promoted collective seeking of a better understanding of the concepts governing the phenomena just observed; because much of the phenomena in open channel hydraulics is counter-intuitive, such discussions make students challenge their own pre-conceived ideas and offer explanations. Students were also asked to explain certain concepts and receive feedback from an instructor or teaching assistant and then refine their explanations of phenomena observed.

Changes between the cohorts can be summarized as follows. There are: 1) macro-changes between teaching methods for the course (not teaching styles between the two professors, just in how the material was conveyed), and 2) micro-changes in terms of allowing the participants to integrate understanding of course material with phenomena observed in the DLM. It is believed that conceptual improvement observed is a direct result of the combination of these two changes. Details of what changed are provided below.

First, macro-changes consisting of the different teaching methods for the course provided a strong base to the study. The control group received traditional lecture style of teaching, which consisted of weekly homework assignments, and passively taking notes during lecture. This is a 'minds on' style of teaching and provides limited opportunity for interaction between 'expert' and 'novice'. Aside from lecture, students are 'on their own' to learn the material at a more detailed level after class consulting the teaching assistant or professor only through limited office hours. Also, the control group received a total of 11 lectures covering the fundamentals of open channel flow. The experimental group received the traditional lecture style method of conveying material for nine lectures and 100 total minutes of interaction with the DLM (or an amount of time for two lectures, totaling an equivalent 11 class periods). The interaction with the DLM provides a time when students (who do not learn best through passive teaching styles), an opportunity to interact with the instructor and teaching assistants. With having two 50-minute DLM sessions in which students can ask questions and have fun learning in addition to traditional lecture to introduce open channel material, improvement of student conceptual understanding of fundamental open channel flow concepts was achieved.

Second, micro-changes consisting of the specific interactions between the DLM and student teams, students with each other and students and the instructor or teaching assistants, contribute to the DLM's effectiveness. During the two DLM sessions, students were given one worksheet for each session. One of the worksheets covered flow profiles and hydraulic jumps, while the other covered flow transitions. Each worksheet had four components: an objective section, a pre-DLM interaction section, a DLM interaction section, and a reflection section. Students were required to read the objective section and fill out the pre-DLM interaction section before the DLM session. Each worksheet consisted of a mathematical component as well as an observational component. Finally, each worksheet was designed to take approximately 35-40 minutes allowing for 10-15 minutes in which students can do anything they would like with the DLM as a form of exploratory learning. Again, the purpose of these worksheets was to provide a guided path for the students to explore the possibilities of open channel flow configurations and fulfill their curiosities. It was not the goal to have each student spend the majority of the time performing detailed calculations.

What separates the DLM from another method that could be equally effective? The DLM is set apart from other methods of active learning by allowing students to have direct interaction with a system that is a small scale version of realistic events that occur in natural and engineered settings. Also, the DLM is capable of having varied flow rates and slopes, and a variety of flow obstructions. Combining the variety of applications that can be viewed within the DLM, the active nature of the learning fostered by this setting, and the strong evidence correlating the DLM implementation with improvements in conceptual understanding based on pre- and post-test results provides a strong case that this method of active learning is effective. In addition, the ability to address misconceptions immediately after observing phenomena in the DLM that may be counter-intuitive adds motivation for implementing this pedagogy. A traditional method of assigning homework and having students wait up to two weeks for feedback from that homework is a lengthy process.

This research is only the beginning point for further DLM development. Although this assessment was primarily developed around open channel flow concepts, there are plans to include an application of pressurized pipe flow to demonstrate the concept of head loss through pipes in parallel and in series. Eventually, the DLM will embody means for other applications beyond pressurized pipe flow and open channel flow to include hydrology (i.e., water movement and distribution techniques).

Finally, we wanted to provide brief commentary relating to the dissemination potential of the DLM and associated curricula. At first the study seems large and difficult to implement, especially for large class sizes. However, our test case had 70+ students and an 18% change of course time allocation to yield a significant increase in student's conceptual understanding. We had the instructor, a graduate student and two undergraduates aid in mobilization and de-mobilization of the DLM's resulting in approximately 10 minutes for setup/take down time. Also the associated curricula are simple to understand and implement with directions on every page. In our case, the worksheets were passed out one week prior to the DLM implementation and had each participant complete section two (DLM Pre-Activity) and read over the associated objectives/goals of the worksheets.

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CHAPTER THREE

IDENTIFICATION OF COMMON MISCONCEPTIONS

1. Introduction

Every engineering student has some sort of life experience with moving water. Therefore, every student in a course involving open channel flow concepts has some sort of constructed understanding of water and how it flows. Research has shown that some of these understandings are incorrect, and cannot be easily corrected [1]. Research on conceptual change can inform why some of these notions are harder to change than others by providing a theoretical framework for understanding the integration of existing knowledge with things that are learned in class. The purpose of this study is to provide insights on students' misconceptions related to open channel flow within the context of the idea of synthetic frameworks developed by conceptual change theorist Stella Vosniadou [2].

2. Background

Although all students have some form of preconceived beliefs about how water could flow from one point to another, their individual beliefs are different from student to student [3]. The difficulty of changing these beliefs is related to how embedded they are in students views of the world. Arguably, the most difficult misconceptions to change are those tied to ontological beliefs [4], [5]. Ontological beliefs are fundamental categories made of the types of things that exist. As a simple example, it would sound odd to discuss how strong red is, because the "red" is not a type of thing that can be strong or weak: we share an ontological belief that "red" is categorized as a "color," and that "strength" is not a regular property of colors. It would be very difficult for students to learn about the relative strengths of different colors until they had undergone an “ontological shift” [6] to re-categorize “colors” as types of things that can be strong.

When students attempt to learn around incorrect ontological beliefs, they can develop what Vosniadou calls “synthetic models.” For example, in her work investigating students’ conceptions of the shape of the earth, students would say the shape of the earth is round, but then indicate that if they walked a long way in a certain direction they would reach the edge [7]. She suggests in this work that students rely on what they have seen and develop ontological commitments based on these observations. For example, students believe that “things are as they appear to be” [8]. In other words, students have developed models of a flat earth through observation but have heard that the earth is round, and integrate both pieces into a ‘synthetic model’. The idea of a flat earth is particularly robust, though, because it is tied to their commitment that things are as they appear to be; in order to truly learn about a round earth, they need to shift their ontological commitment to things (i.e. the Earth) being as they appear to be (i.e. flat).

This study identified common misconceptions in open channel flow concepts in a junior level water resources engineering class at a public university, and interpreted these misconceptions within the context of ontological categories and synthetic models. The broader study included hydraulic and energy grade lines (HGL/EGL); flow transitions; flow profiles; identification of supercritical/critical/subcritical flow along an open channel; and hydraulic jumps. However, this article focuses on the results from the broad crested weir questions.

3. Methodology

3.1 Course Structure

The course of interest focused on water resources at a public university and is composed of three different main sections in the following order: pressurized pipe flow, open channel flow, and hydrology. However, participants were only interviews about open channel flow concepts. Also, to be enrolled in the course, all students had to have completed the fundamental prerequisite course, fluid mechanics. The prerequisite course briefly covers the fundamentals of open channel flow such as laminar and turbulent flow, but does not detail anything related to the tested concepts. Lastly, the course was based on a popular textbook that details the fundamentals of the three topics that compose the course.

3.2 Participant Selection and Interviews

Students that participated in this study were selected in order to include students from the top, middle and bottom quartiles in terms of academic performance, and were interviewed in a random order. The class is primarily composed of junior level students with the exception of few senior standing students. Only civil engineering students were enrolled in the course and participated in the interviews. We asked each participant to not discuss or reveal any of the interview questions to other classmates so internal validity would remain strong. Finally, the participants were told that a key containing the correct answers and detailed responses to each question asked would be provided at the end of all the interviews.

During Spring 2011, 50 undergraduate students were interviewed using an open-ended interview method over a period of two weeks. Interviews followed a typical protocol that was semi-structured and allowed for probing questions related to difficult topics of open channel flow. The instructors identified the difficult concepts that compose the interview questions before this study began and the concepts were based from their previous knowledge, experience, and course notes. Interview packets were composed of a six-page handout that contained five questions related to open channel flow and one question related to pressurized pipe flow. The pressurized pipe flow was question number one and held the purpose of an introductory question to allow students to become familiar and comfortable with the interviewing process. The remaining five questions covered the fundamental concepts of open channel flow in the following order: hydraulic and energy grade line; the most efficient section; transitions; flow profiles (broad crested weir results); and hydraulic jumps (sharp edged weir results). Figure 9 below outlines the order of the interview packet and related questions.

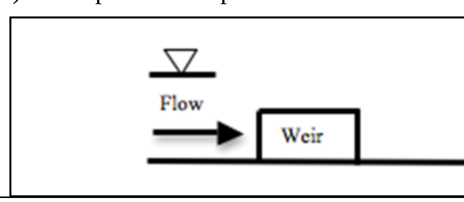
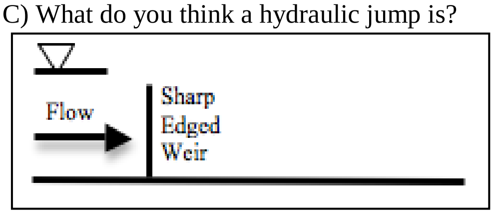
Concept	Questions Asked
Pressurized Pipe Flow	A) Draw the HGL and EGL from points A to B. B) Write the energy equation from A to B. C) How would you figure out how much water flows from A to B?
Open Channel Flow – HGL/EGL	A) Draw the HGL and EGL from points A to B. B) How would you figure out how much water flows from A to B? C) Write the Energy Equation between A and B.
Most Efficient Section	A) What is the most efficient section, A - D? B) How would you define the most efficient section? C) How many variables control most efficient section for figures A – D?
Specific Energy	A) How does water flow downstream? B) How does the specific energy change between points one and two?
Flow Profiles	A) Draw the flow profiles for A – D. B) Label places of super/sub/critical flow 
Hydraulic Jumps	A) Draw the flow profiles for A – D. B) Label places where a hydraulic jump occurs. C) What do you think a hydraulic jump is? 

Figure 9. Interview protocol standard questions and order.

3.3 Analysis Techniques

One graduate student coded all 50 interviews in a qualitative coding software program to prevent any inconsistencies within the data. The same graduate student transcribed three of the 50 open-ended interviews; a professional company transcribed the remaining 47 interviews.

Coding software was used to separate the collected data into common groups. A code is a piece of data that holds information of interest. In this specific case, when participants indicated preconceptions through using words such as ‘built up’ or ‘previous experience’, those statements were given a code. Once the data were coded for preconception evidence, data that held similar codes were grouped together to create a node. The process that was used is outlined below:

The first step in the analysis was simply to identify correct and incorrect responses to each interview question. The interviews were structured so that most questions had a clearly correct answer, such as the specific shape of the flow profile over a weir. Participant responses that were fundamentally correct, but lacked pertinent details (for example a flow profile in which the differences in water elevations were slightly too exaggerated, or where the area of critical flow was incorrectly identified) were still marked as "correct" for the purposes of this study.

The second step included differentiating the incorrect answers provided by the participants from step one. Although many students provided slightly different answers to a single question, the stated answers only differed by a small amount. Therefore, if similar answers were globally the same, they were grouped together.

Once the incorrect answers were grouped, specific words related to preconceptions were identified and coded. Many participants used common fundamental language such as ‘subcritical flow’ and ‘uniform conditions’. When a participant stated they gave their answer based from previous experience or if they used words that were very primitive such as ‘lift’ or ‘build up’, the answer was coded, as those words were not taught during lecture.

Finally, once specific words and/or phrases were identified, more nodes were made to group common words together. For example, students that indicated their answer was based from previous experience were grouped together in relation to a specific answer. From the nodes, individual answers are analyzed in detail and specific quotes are pulled out to represent a common misconception and used in the results/discussion section.

The results detailed in the next section were a product from this process, and serve as an introductory to identifying what is difficult for students to understand.

4. Results

4.1 Content Review

A broad crested weir is essentially a three-dimensional rectangular block that crosses the full width of a channel and can vary in length. Participants were given the upstream water surface elevation and details shown in question 5 in Figure 9 previously, and asked to draw and explain the flow profile. Figure 10 below shows the correct flow profile.

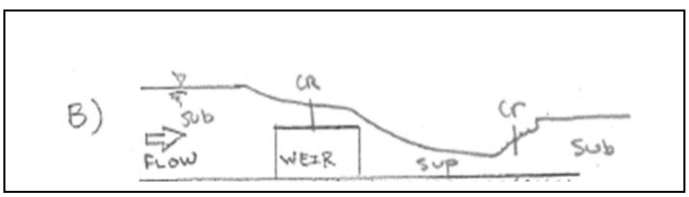


Figure 10. The correct flow profile for a broad weir.

The various changes in flow depth and velocity shown in Figure 10 can only be explained in terms of changes in the specific energy, and the complex interrelationships between specific energy, inertial forces and gravity forces. Upstream water was in a subcritical condition, which would result in a transition to supercritical flow after the weir and critical flow at some point over the weir. Subcritical flow is located in the upper curve (1) of the specific energy curve as shown in Figure 11 below. As the fluid travels over the weir, it transitions energy from static (depth) to inertial (velocity) and transitions to point 2 on the specific energy curve (supercritical flow). Eventually, inertial forces would decrease due to friction on the channel bottom, causing a shift from curve 2 to curve 1 in Figure 11. This appears as the hydraulic jump shown downstream of the weir in Figure 10.

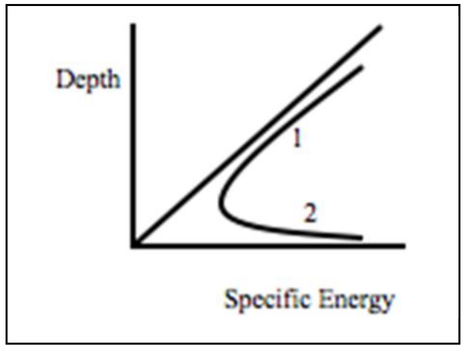


Figure 11. The specific energy curve. 1 is subcritical, 2 is supercritical flow.

4.2 Results and Discussion

Forty percent (20/50) of students drew the correct flow profile. Among the incorrect answers, the most common misconception was that the depth increases over the weir, then decreases after the weir. Figure 12 shown below is a common misconception identified through the open-ended interviews. As you can see, the water level rises over the weir, and then decreases after the weir despite the fact that this participant labeled subcritical flow before the weir. This participant indicated that critical flow would occur at the middle point of the weir, which is incorrect as the water level increased and did not transition to supercritical flow over the weir.

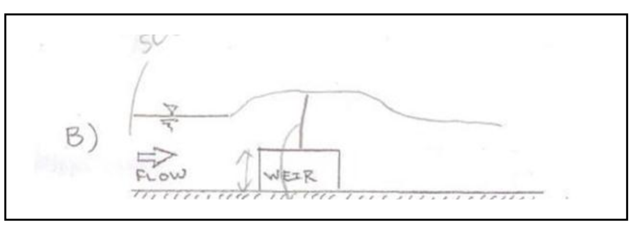


Figure 12. Common student drawing for this flow profile.

The following excerpt is typical of many students' explanations of this incorrect flow profile:

Student 1: Oh, boy. So we're going to go over this weir. I think it kind of might hump up a little here. We have some, I don't remember what it's called, it's backflow…

Interviewer: Why do you think it humps up like that?

Student 1: Well, sometimes, there's that- I'm not remembering the term, it's basically gets- it can't go over this fast enough and so it kind of gets that buildup, it's that kind of- I can't remember the term but it kind of builds up on the back side there a little bit, builds up some energy. So then, anyway, over a weir, we'd probably kind of get the same, just depends on the speed and stuff.

In terms of ontological categories and synthetic models, there are three significant components to this common incorrect answer: (1) the use of sequential language, (2) the emphasis on two linked variables, and (3) the image of a process with initiation.

1) Sequential Language

Some participants justified their flow profile as a logical chain of events in time with the latter events being caused by the former, or as a sequential process unfolding along the profile, with downstream events being caused by upstream conditions. For example, consider the following student quotes explaining their incorrect fluid profiles:

Quote 1: "*Okay. I know that it [the fluid] would hit the weir, and it would flow choke at least a little bit until it increased, and then as it goes over the weir, it would actually start going down*."

Quote 2: "*We have flow-choking occurring right here. Water is going to kick up against the weir, push back up from the subcritical and then force down to supercritical.*"

Quote 3: *"So it's fallen in, it hits the weir; it wants to go over the weir."*

Quote 1 appears to explain the process as a temporal sequence: first the water hits the weir, then the "flow chokes," then it goes over the weir and finally "it would actually start going down." Quote 2 appears to be more spatially oriented and indicates locations along the profile where the water "kicks up" or is "forced down."

Characterizing flow over a weir as a sequential process is an ontological commitment: this phenomenon is the kind of thing that can best be explained by a list of events in which the order has causal significance. This misconception leads the students to create synthetic models to justify incorrect answers with concepts learned in class. Quote 2, in particular, correctly emphasizes the importance of subcritical and supercritical flow, but the ontological commitment to a sequential process leads to misidentifying then with different steps in the process, rather than fundamentally different physical processes.

2) A Two Variable System

Many students strove to find relationships between two (and only two) variables to explain their flow profiles. This misconception often, although not always, co-occurred with the two other misconceptions described here: for example quote 1 attempts to describe the flow profile as a relationship between the weir and flow depth. As exemplified in the following quotes, this relationship was the most common one, although velocity and energy were sometimes also invoked:

Quote 4: "*I'm not remembering the term, it's basically gets- it can't go over this fast enough and so it kind of gets that buildup.*"

Quote 5: "*There'd be a jump initially at the weir, because it's going to push it up and afterwards it's going to go lower because the velocity will increase it, putting it lower.*"

Quote 6: "*This weir slows down the energy right here so the pressure decreases and it drops in level.*"

As a result of some students holding this framework knowledge, the system is composed of two things rather than a multitude of forces that contribute to how a fluid flows over a broad crested weir. These quotes also provide evidence that some students may not view an open channel system as a constrained system. Due to their ontological beliefs about the nature of open channel flow, these students are satisfied with their two-variable explanations – and indeed may be intentionally simplifying their answers in recognition of the value of parsimony. Ideally, the students' explanations would lead them to realize a flaw in their logic – quotes 4 through 6 do not explain the drop in water level predicted, for example. This is strong evidence for, and a product of, the students' synthetic models because there is a fundamental mismatch between the concepts applied, and the framework in which they are applied. Quote 6, for example, is technically correct in attempting to explain the profile in terms of energy, and is confounded by the synthetic model where energy can "slow down" at one location.

3) Process with initiation

Finally, many participants explained their profiles in terms of a process that had been initiated; some students indicated their answer was as a result of the fluid starting to flow after the weir was placed in the channel.

Quote 7: "*Okay. For this one you have flow coming into the channel, and into the weir. It's going to hit this and it will force super critical here. It will come down.*"

Quote 8: "*I guess I would only put a weir into a system that's already in subcritical flow. I don't know why I think that, but that's just what I think, and so it would force the flow to go down to critical at some point.*"

Quote 9: "*Because it needs to cross over the obstruction and the amount of flow decreases. It's all of a sudden obstructed.*"

Rather than looking at the instantaneous point in time, which would be ideal to draw the flow profile, these participants indicated that they working with a dynamic model that began after placing the weir into the system. Quotes 7 and 9 show this clearly by indicating the system has flow "coming into the channel" which is "all of a sudden obstructed." Again, this approach often co-occurred with the ontological belief that flow over a weir is a sequential process: this is logical as a sequential process needs some kind of special initiation to being the causal chain. Students' preference for this type of reasoning is particularly interesting in light of the fact that all students were specifically instructed to consider the system in steady state. This mismatch between fundamental characteristics of the system (steady state, complex, conservative of mass and energy) and approaches to explanation is, again, evidence of the students' synthetic models.

4.3 Evidence of Misconceptions with Sharp-Crested Weirs

These misconceptions were reiterated in many cases in the context of sharp edged weirs. A sharp edged weir is essentially a thin broad crested weir. The correct profile of a sharp edged weir can be seen in Figure 13 below. As the water flows over the weir, it immediately drops (unless there are flood conditions upstream or downstream) and transitions from subcritical to supercritical flow.

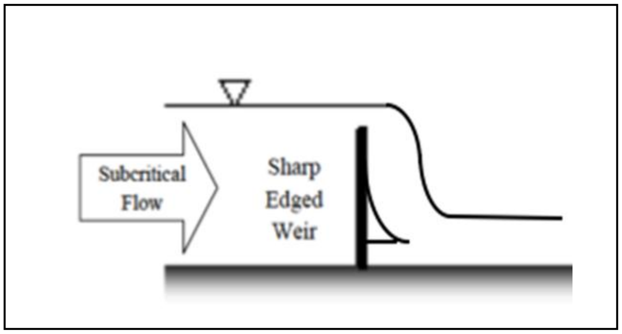


Figure 13. The correct profile for a sharp edged weir. Student two made very similar statements in relation to a sharp edged weir. Figure 6 is a picture of what student 2 drew.

Student 2: For B there'd be a jump initially at the weir, because it's going to push it up and afterwards it's going to go lower because the velocity will increase it, putting it lower.

Interviewer: Why do you think the weir wants to push the water up?

Student 2: Because it has a constant flow initially. Has a constant flow and then it's you know hitting basically an object right there so it's got to go somewhere so it's going to go up first.

This exchange shows Student 2's characterization of the flow as a sequential process ("afterwards it's going to" and "then it's, you know, hitting basically an object") featuring two primary variables (the weir and flow depth) to describe a process that has been initiated when the weir was introduced to the flow channel.

Student 2: For B [the sharp edged weir], because the weir is right there, the water underneath is going to have to jump up once it hits it, and so that is why there's a jump right there, and then after the initial jump, since there's nothing else the rest of the way, it's going to kind of even out.

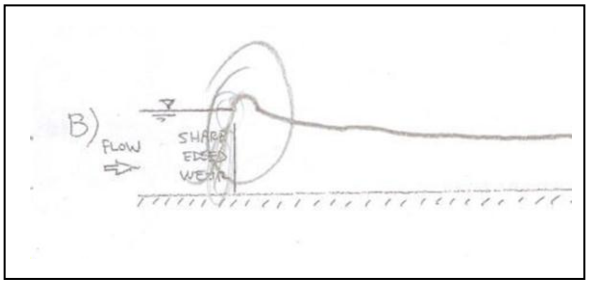


Figure 14. The incorrect flow profile drawn by student 2.

Again, this explanation relies heavily on working through the process sequentially with reference to two key variables (this time the weir and the “jump”) and the initiation of the process (“have to jump up once it hits it”).

5. Discussion

There are interesting and potentially fruitful parallels between the misconceptions and synthetic models identified here and Chi’s theory of direct versus emergent causal narratives [3]. Chi argues that one particular type of ontological belief is responsible for many misconceptions: the incorrect categorization of “emergent processes” as “direct processes.” In her terminology, a direct process is one that is intentionally initiated by a causal agent and follows a logical pattern directed at achieving an end state. An example of a direct process would be when a teacher instructs a group of students to line up, and then they do so. In contrast, and emergent process is one in which an observable phenomenon is actually caused by ongoing, non-directional and unobservable interactions that do not directly affect nor are they directly affected by the observable phenomena. An example of an emergent process would be if, in a roomful of students, every student wants to maximize the distance between him-or-herself and the whiteboard along one wall. After a while, the students would end up lined up along the opposite wall – not because they wished to form a line, but because each individual student would continue moving until they felt they could get no further from the whiteboard. Note that the students' desire to be away from the whiteboard does not have a necessary beginning, and does not change or end when the students form a line – it is simply a property or characteristic behavior of the students that, in some circumstances (a whiteboard along one wall of a room) results in students lining up.

In our findings, the flow profiles are equivalent to the students' line. The students' interviewed seem inclined to identify special causal agents (the weir, or the installation of the weir) and sequences of events, which suggests they tend toward a direct causal explanation. The correct explanation of the flow profiles is more emergent, however, in that the fundamental processes do not have beginnings, or sequences, and are not intentionally causing the observable phenomena of interest.

6. Conclusions

The identification of common misconceptions of open channel flow concepts is important and provides a way to qualitatively understand what the majority of students are having difficulty learning, and potentially whey they are having these difficulties. Determination of these misconceptions is particularly compelling in light of the fact that these students' misconceptions have very likely been directly contradicted in their classrooms, homework and exams. Identifying other preconceptions can help further the validation of the argument presented here that students are operating incorrectly within a 'direct' process ontological category. .

Some of the language that students' used to describe this process indicate that they may draw off of analogies with solid objects. For example, some students say the water 'steps up' the weir, as if it was a 'chunk' of water and not a viscous fluid. This is further evidence of direct and linear process thinking. Future research in other areas of fluid mechanics could investigate how and when students' use these analogies.

Additional research is needed to help reduce the current popular approach of addressing long lists of misconceptions, with varying results. Research utilizing theories of conceptual change and ontological categories could lead to approaches to instruction, such as ontological training, that address several misconceptions with one instructional approach.

The identification of common misconceptions of open channel flow concepts is important and provides a way to qualitatively understand what the majority of students are having difficulty learning. Further, identifying any preconceptions can help professors teach more efficiently and effectively.

The results provide clear evidence that students are having difficulty understanding the fundamentals of open channel flow concepts. Whether this is due to lack of proper instruction, preconceptions and misconceptions are hindering the ability for these students to remotely understand open channel flow concepts. Although some concepts are easier and more intuitive than others, the global them of the results is that students are having difficult understanding basic concepts as well as counter-intuitive concepts.

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CHAPTER FOUR

CONCLUSIONS

There are two important conclusions that can be drawn from the results and discussion commentated on in previous chapters two and three: 1) the Desktop Learning Module and accompanying worksheets were effective in helping students think more critically and 2) the identification of three incorrect cognitive processes related to fundamental open channel flow concepts. Each conclusion is commentated in more detail below.

When reviewing the results from the effectiveness of implementing the DLM and accompanying worksheets, three supporting pieces of evidence support the finding that improvement was seen across all questions at an increase of approximately 30%. First, there were multiple perspectives that showed an increase in conceptual understanding. Improvement was shown to be statistically significant through applying a standard t-test and observing the p-value for all questions. Each question aside from the control had a p-value less than 0.05, which supports that student's conceptual understanding considerably improved for the experimental group. Second, improvements were not just seen quantitatively, but qualitatively as well through students written explanations of their answers related to each question. After the brief interactions with the DLM, many students showed an increase in technical and critical thought through justifying their answer utilizing the fundamentals of a system taught during the course. Third, although participants in the experimental group scored lower on the pre-test than the participants in the control group, they out-scored the control group participants in the post-test. This is strong evidence that contributes to support the effectiveness of the DLM and accompanying worksheets.

A great amount of information regarding the actual cognitive processes behind student's answers was identified using the open-ended interviews and there are two supporting pieces of evidence that contribute to the identification of conceptual difficulties and incorrect cognitive processes. First, the identification of common areas of conceptual difficulties were found in all concepts of open channel flow. Although some concepts showed a smaller number of students answering incorrectly, other concepts indicated that most students were having difficulty understanding. Second, when attempting to understand the reasoning as to these areas of conceptual difficulties, three cognitive processes were found: sequential language; a process with initiation; and a sequential process. Not only are these three processes incorrect cognitive progressions, but also they are often accompanied with simplistic student language that counters the language of an open channel system. For example when students use the terminology ‘water wants to step up over a weir’ rather than ‘water flows over the weir’.

Overall, there was an incrase in the conceptual understanding when comparing the control and experimental cohorts. The amount of class time changed was minimal at approximatlely 18% and the implementation of the DLM and associated curricula worked together to improve students’ conceptual understanding. This research provided a foundation for further studies and explorations into the full capabilities of the Desktop Learning Module as eventually the course of interest could be completely taught with the DLM in conjunction with lecture to introduce the concept of interest.