

Development of Bloom's-level Graduated Instrument for Assessing Transport Concepts in Hands-on Learning

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Bio-sketch

Aminul Islam Khan has received B.Sc and M.Sc in Mechanical Engineering from the most regarded and reputed engineering university of Bangladesh, Bangladesh University Engineering and Technology (BUET). In his B.Sc degree, he had received the department Gold medal for his outstanding achievements.

Aminul Islam Khan has joined to BUET in 2011 as a Lecturer in Mechanical Engineering Department. In 2015, he has become an Assistant Professor in the same department of BUET. In 2016, he has joined to School of Mechanical and Materials Engineering of WSU as a PhD student. From that time, he has been working as a Research Assistant. As a research assistant, he has been working to improve learning/teaching methods in undergraduate engineering education along with his scientific research. He is currently working on drug delivery approach modeling for treatment of neurodegenerative diseases.

Aminul Islam Khan is committed to excellence in teaching as well as research and always promotes a student-centered learning environment. He has a keen ability to teach, advise, and recruit students. He has also proven himself to be a very effective researcher by publishing several journal articles. His resume has a substantial list of publications, including peer-reviewed articles in national and international journals and conferences. Moreover, he has joined in several reputed conferences, for example American Physical Society (APS), and presented his scholarly works.

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Kitana Kaiphanliam is a first-year doctoral student in the Chemical Engineering program at Washington State University (WSU). Her research interests include biomanufacturing for immunotherapy applications and miniaturized hands-on learning devices for engineering education. Kitana is an active member of the American Institute of Chemical Engineers (AIChE) at WSU, and serves as their Graduate Student Chair for the 2018-19 academic year.

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Prof. Bernard J. Van Wie received his B.S., M.S. and Ph.D., and did his postdoctoral work at the University of Oklahoma where he also taught as a visiting lecturer. He has been on the Washington State University (WSU) faculty for 36 years and for the past 27 years has focused on innovative pedagogy research and technical research in biotechnology. His 2007-2008 Fulbright exchange to Nigeria set the stage for him to receive the Marian Smith Award given annually to the most innovative teacher at WSU. He was also the recent recipient of the inaugural 2016 Innovation in Teaching Award given to one WSU faculty member per year.

Dr. Olusola Olalekan Adesope, Washington State University

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Using Bloom's Taxonomy for Transport Phenomena Question Development: A Method to Improve the Assessment of a Hands-on Learning Pedagogy

Abstract

Each engineering student who enters a fluid mechanics and heat transfer course has his or her own perception of transport phenomena, where the foundation of those perceptions could be built on previous coursework or experiences. As student progress through these courses, they build on such perceptions and develop a better understanding of the subject. Often, though, there is a lack of depth in knowledge of fundamental transport phenomena concepts. This level of understanding is necessary for enduring effects on student abilities. From data and literature, it has been proven that hands-on learning is more effective than passive learning in developing depth in conceptual understanding. As a result, low-cost desktop learning modules (LC-DLMs) were developed to enhance student understanding of various fundamental transport phenomena concepts: hydraulic loss, energy transformations in fluid flow, and heat exchange. However, there is a lack of robust measures for assessing student understanding. To address this gap, Bloom's taxonomy can be used to categorize learning outcomes, measure learning gains, and better analyze understanding of concepts embedded in use of exercises that involve the LC-DLMs. This method provides a novel means to predict areas of misconceptions and create corrective measures to address those misconceptions. The goal in this paper is to explicate the development of Bloom's-based questions to help students achieve a proper understanding of different transport phenomena through LC-DLMs. A detailed outline of the development of Bloom's taxonomy-based questions is provided to ensure a concrete base for quantitative assessments. Results from preliminary evaluations of those Bloom's taxonomy graduated questions, along with the implications and limitations of these results are provided.

1. Introduction

*“Tell me, and I forget.
Teach me, and I may remember.
Involve me, and I learn.”*
- Benjamin Franklin

There is compelling research that proves, in many instances, students who are taught using hands-on instruction methods with manipulatives outperform those who are not [1-5]. Our group has viewed this in light of theories about learning [3] including the Interactive Constructive, Active, Passive (ICAP) hypothesis [6], Anderson’s Information Processing Theory [7] and cognitive load theory [8]. Many have referred to a piece by Dale [9], where he makes reference to a ‘cone of experience’ or ‘cone of learning’, and provided an intuitive model of the concreteness of various kinds of audiovisual media used for learning. The actual percentages of learning retained as a result of the activities represented in the ‘cone’ have been refuted [10]. However, educational researchers acknowledge that the varied levels of student involvement each have their place in the learning environment [11] including lecture, reading, demonstrations, discussion, and hands-on activities (doing). More complex and intermingled concepts seem to be better learned when students are engaged at the higher Bloom’s levels [3]; at these higher levels, hands-on learning is more effective than the traditional learning methods and can improve the learner’s long-term memory which is essential for the analysis of new or more complex information [12].

Hands-on learning is a pedagogy that directly involves the learner by actively inspiring them to do something in order to learn about it. Our team has designed a variety of hands-on learning devices called Low-Cost Desktop Learning Modules (LC-DLMs) to provide an integrated learning method for various fluid mechanics and heat transfer processes. LC-DLMs can be powerful tools to provide a comprehensive foundation of fundamental fluid mechanics and heat transfer concepts, which can help form a robust understanding of concepts necessary to build further knowledge. The importance of hands-on learning through LC-DLMs has been demonstrated through several years of implementations of various modules such as hydraulic loss, venturi, and double pipe, and shell & tube heat exchangers [1, 3, 4, 13-16]. However, through these studies, we found there is a lack of vigorous measures for assessing the students’ level of understanding.

Concept inventories (CIs) are frequently used assessment tools designed to determine the degree to which students understand the major concepts of a subject [17, 18]. CIs utilize multiple-choice questions (MCQs) and specifically designed response selections to help identify misconceptions. CI fail, however, to provide evidence of the causes of the misconceptions or the nature of student conceptual understanding [19]. Although MCQ-based CIs can measure student learning and understanding, they do not provide measures of higher-level thinking. For example, Ngothai and Davis [18] developed and analyzed a novel Chemical Engineering fundamentals CI which displays areas for constructive development; however, their CI fails to identify levels of student misconceptions and does not provide a measure of higher-level thinking. It has been found that textual analysis on student written explanations can provide better judgements of their conceptual understanding. Goncher and Boles [19] described a framework to analyze assessment instruments that utilize textual, short-answer responses. However, their framework has not yet been tested for large sample sizes. In addition, similar to MCQ-based CIs, this framework does not measure the

understanding levels against theoretical educational theories such as Bloom's taxonomy of learning [20] or cognitive load theory [21].

Moreover, there are few CIs specifically developed to assess understanding of fluid mechanics and heat transfer concepts. We, therefore, developed an assessment tool—similar to a concept inventory—based on Bloom's taxonomy to improve assessment of hands-on learning instruments. Our questions are formulated in a similar manner to CIs; we initially identify common misconceptions that arise from traditional classroom teaching. However, unlike CIs, we do not only identify the misconceptions, but we also educate students based on their misconceptions through visual experiments performed on LC-DLMs. In addition, we categorized the questions according to Bloom's taxonomy so that the impact of LC-DLMs can be assessed at both low and high cognitive learning levels. Thus, this provides the level at which misconceptions are present and serve to guide corrective measures to eliminate these misconceptions. Besides that, while designing the assessment tool, we also incorporate knowledge about cognitive load theory so that the elements of the questions do not overflow the working memory. The importance of Bloom's taxonomy in characterizing a student's level of learning and creating appropriate question based to guide an inquiry has been demonstrated in various fields of study [22, 23]. We hypothesize that the assessment tool described herein will allow us to evaluate to what level students have mastered core engineering concepts, as well as, measure gaps in understanding and further identify student misconceptions.

2. Bloom's Taxonomy

Bloom's taxonomy describes an order of cognitive-learning levels ranging from knowledge and comprehension of specific facts and conventions to more advanced levels of synthesis and evaluation. Originated in 1956 it was developed to evaluate and characterize a student's level of understanding and abstraction, and provides classifications and descriptions of six different levels of intellectual behavior important in learning [24] including knowledge, comprehension, application, analysis, synthesis, and evaluation in the cognitive learning domain. These categories were arranged from simple to complex and from material to abstract. In addition, it was assumed that the original taxonomy represented a cumulative hierarchy; that is, mastery of each simpler category was a prerequisite to mastery of the next more complex one.

A revised version of Bloom's taxonomy, developed by a former student of Bloom, converted the original category titles to their active verb counterparts: remember, understand, apply, analyze, evaluate and create, and changed the order of the top two levels [25]. Crowe et al. [22] implemented Bloom's taxonomy to enhance student learning in biology by creating the Blooming biology tool. They described what types of questions can be asked at each level of Bloom's taxonomy. Usually, multiple choice questions are not suitable for the "create" level for example. Therefore, either short answer or essay type questions are asked at this, as well as for the "evaluate" level. This also explains why conventional MCQ-based CIs are not suitable for evaluation of the higher Bloom's levels such as create. Table 1 provides the descriptions, associated verb, question types and example questions related to the LC-DLMs for each Bloom's level.

Our goal is to provide students with a comprehensive understanding of different complex transport concepts through visualization and hands-on experiments, as we wish to evaluate student learning

at higher Bloom’s levels using our assessment tool. Moreover, we aim to create an assessment tool that can be completed in approximately 10 minutes, so the inclusion of short answer type questions is difficult as they typically take several minutes to answer appropriately. To balance these two aims, we created questions to ask students to choose the best answer to a multiple-choice question, then answer a second multiple choice question and/or write a short answer to justify the first answer. In this way, we believe we are creating, in this ongoing research, a tool that assesses student understanding up to the “evaluate” level of learning.

Table 1: Bloom’s Taxonomy-based tool for LC-DLMs¹

| | Remember | Understand | Apply | Analyze | Evaluate | Create |
|---|---|--|---|---|--|---|
| Definition | Retrieving relevant knowledge from long-term memory | Determining the meaning of instructional messages, including oral, written, and graphic communication | Carrying out or using a procedure in a given situation | Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose | Making judgments based on criteria and standards | Putting elements together to form a novel, coherent whole or make an original product |
| Associated verbs | Select, list, name, define, describe, memorize, label, identify, locate, recite, state, recognize | Extend, illustrate, match, explain, express, interpret, restate, defend, interrelate, paraphrase, summarize, rewrite | Organize, paint, sketch, choose, generalize, show, apply, produce, dramatize, draw, solve, prepare, predict | Compare, analyze, differentiate, subdivide, categorize, prioritize, dramatize, draw, distinguish, classify, infer, point out | Judge, relate, evaluate, support, appraise, weight, criticize, recommend, consider, critique | Compose, construct, combine, organize, originate, hypothesize, produce, plan, develop, design, create, invent |
| Type of question | Labeling, Fill-in-the-blank, True-false, Multiple-choice, Short answer, Essay | Labeling, Fill-in-the-blank, True-false, Multiple-choice, Short answer, Essay | Labeling, Fill-in-the-blank, True-false, Multiple-choice, Short answer, Essay | Fill-in-the-blank, True-false, Multiple-choice, Short answer, Essay | Multiple-choice, Short answer, Essay | Short answer, Essay |
| Example questions related to LC-DLMs | Identify the parts of a double pipe heat exchanger; state the continuity principle | Explain the physical meaning of Fourier’s law of conduction or Bernoulli’s equation | Apply continuity or Bernoulli’s equation to find a specific parameter | Predict what happens to heat transfer if thermal conductivity increases | Criticize the current designs of heat exchanger DLMs and describe your ideas for improvement | Design your own heat exchanger which will transfer a specific amount of heat from hot to cold fluids |
| Characteristics of multiple-choice questions | Requires students to recall specific information gained from the lesson | Requires students to go past simply recalling facts, and instead, they need to understand the information | Requires students to predict the outcome of a new problem with the information they have gained in class | Requires students to interpret the data and select best answers | Requires students to assess information and come to a conclusion about its value or the biases behind it | N/A |

¹Modified from references [3, 22, 25]

3. Transport Equipment and Associated Concepts

Heat transfer and fluid mechanics are core engineering science areas that are studied in many disciplines including Chemical, Mechanical, Civil, Aerospace, Biomedical, and Environmental Engineering. Often, though, there is a lack of depth in knowledge of fundamental transport phenomena concepts. To address this lack of understanding, LC-DLMs were created to provide an opportunity for students to complete hands-on experiments in a classroom environment to learn the fundamental aspects of fluid flow and heat transfer. In addition, LC-DLMs make it possible for engaging conversation in fluid mechanics and heat transfer courses. Moreover, the cost of LC-DLMs is comparable to that of a textbook which makes it possible for groups of students to

purchase their own modules and conduct independent research on fluids and heat transfer phenomena. For the current NSF sponsored Improving Undergraduate STEM Education (IUSE) project, four LC-DLMs have been manufactured and are being utilized in classroom implementations: hydraulic loss, venturi meter, double pipe heat exchanger, and shell & tube heat exchanger. Details of the concepts addressed during use of each module are provided in Table 2.

In brief, LC-DLM usage occurs as follows: when a topic such as hydraulic loss is introduced in the classroom as lecture, students take a pretest which measures their current understanding of the associated concepts. The students are then put into groups of about 3-5 and use the corresponding LC-DLM to conduct mini-experiments. During these experiments, they discuss the associated concepts and follow/fill-out a worksheet. The LC-DLMs provide a visual and qualitative description of the concepts, whereas the worksheet provides means for introducing quantitative understanding of the concepts. After this, students take a posttest which provides quantitative measurements of understanding of the associated concepts. Both pre- and posttest are taken on Qualtrics, a survey software.

Table 2: LC-DLM modules and the major fluid mechanics or heat transfer concepts addressed through the use of each module

| Module | Major Concepts Addressed by Module |
|--|---|
| Hydraulic loss system | <ul style="list-style-type: none"> • Physical features • Hydraulic loss • Friction • Mass conservation |
| Venturi meter | <ul style="list-style-type: none"> • Physical features • Continuity (mass balance) • Mechanical energy balance • Flow work • Kinetic energy • Hydraulic loss • Friction • Bernoulli's equation |
| Double pipe and shell & tube heat exchangers | <ul style="list-style-type: none"> • Physical features • Energy balance • System boundaries • Log mean temperature difference (LMTD) • Parallel (co-current) and counter (counter-current) flow • Temperature driving force • Purpose of baffles (for shell and tube only) |

4. Development of Assessment Questions

Students who enter a course, begin with some foundational knowledge and intuition built upon prior exposure to similar material or their own perceptions about the physical world. As they progress through their courses, they build on their initial views and develop a newer, typically more accurate, understanding of the phenomena. However, often their views are not complete and in addition, they often don't fully understand new complex information about phenomena as it is introduced in class. As a result, they may have a weak grasp of the basic concepts underlying the physical phenomena which are displayed and retain misconceptions about the subject matter.

Through an analysis of faculty interviews and student data collected over the past several years during implementations of LC-DLMs at different universities, we have identified many of the misconceptions surrounding transport phenomena [15, 26]. For example, a common misconception related to the venturi meter is that the pressure should go up as the liquid flows through the venturi throat because it is being “squeezed”. During the implementations, many students are surprised to see the pressure drops instead of rising at the throat of a venturi meter. Thus, some of the misconceptions are automatically addressed by the inherent visual design of the LC-DLMs.

Additionally, we have explicitly addressed other misconceptions by adding new features to our original LC-DLMs. For instance, many students believe that the velocity should reduce in the throat of the venturi due to contraction and therefore increased resistance due to a squeezing effect. To address this misconception, we have, in the past, instructed students to place small plastic beads into the inlet of a venturi meter to observe the velocity at different points. As another example, when we asked students to predict the velocity for flow down the connecting pipe from an overhead beaker of a gravity fed design of the shell and tube heat exchanger shown in Fig. 1A, most of them predicted an exponential increase in velocity because of their misconception about gravitational forces and fluid continuity. To address this misconception, we have come up with a pump fed design for shell and tube heat exchangers shown in Fig. 1B that prevents students from assuming that the velocity changes in the inlet pipe; although, this can also be addressed by measuring the rates of depletion and filling of overhead and exit reservoirs, respectively.

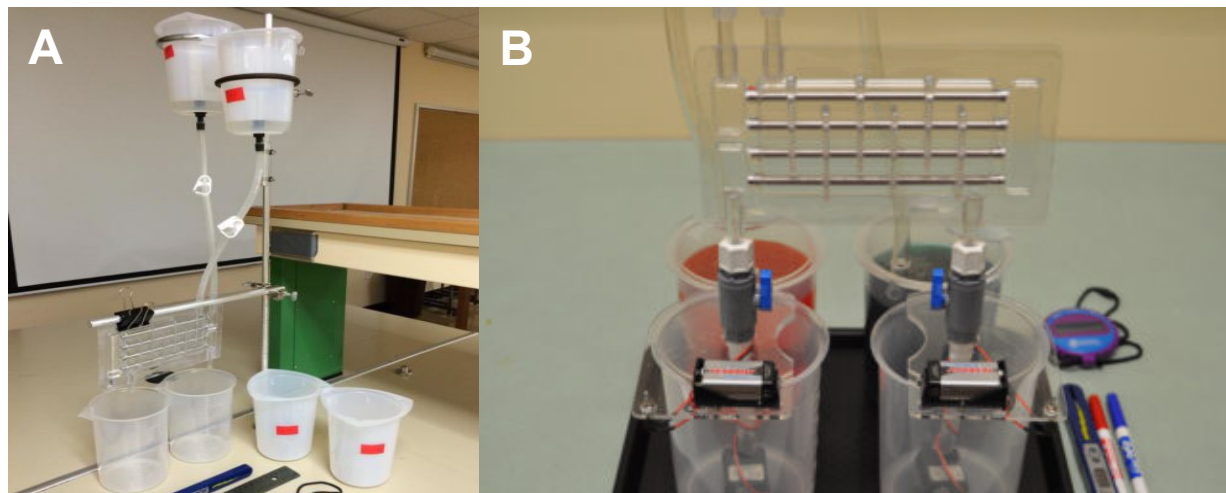


Figure 1. Shell & tube heat exchangers: A) older gravity fed system and B) newer pump fed system (Figures are taken from the website located at <https://labs.wsu.edu/educ-ate/> website).

However, even after LC-DLM design, manipulations and careful development of experimental procedures, we find there are still several misunderstandings of basic concepts. To address these gaps, we developed Bloom’s-based questions to specifically identify misconceptions, categorize learning outcomes, measure learning gains, and better analyze levels of understanding of concepts relative to the LC-DLMs in hopes that the LC-DLMs can be further improved to best suit student needs.

As stated before, a pre- and posttest are given to measure the student levels of comprehension before and after the LC-DLM experiments. In the posttest, though, higher Bloom's level questions that were not in the pre-test can be introduced, which will provide a measure of determining if the LC-DLMs help students achieve higher-level thinking. Under this Bloom's-Taxonomy-based question development, the higher-level questions are designed by extrapolating the concepts addressed by the LC-DLMs into a scenario that the students have not been exposed to prior.

In the Venturi LC-DLM, students can see and quantify the effect of gradual contraction, followed by gradual expansion, on the pressure and velocity profiles along its length. Although this addresses the misconceptions about the pressure reduction and velocity increase at the venturi throat, this learning can be further extrapolated to further encourage students to learn about energy conservation that coincides with the pressure drop and velocity increase. For example, a question based on pressure and velocity distribution can be asked in the case of a sudden expansion followed by a contraction in a pipe flow arrangement as shown in Fig. 2. This scenario is completely opposite of what students are exposed to in the Venturi LC-DLMs, thus making it a higher Bloom's-level question that challenges the Venturi-related misconceptions directly.

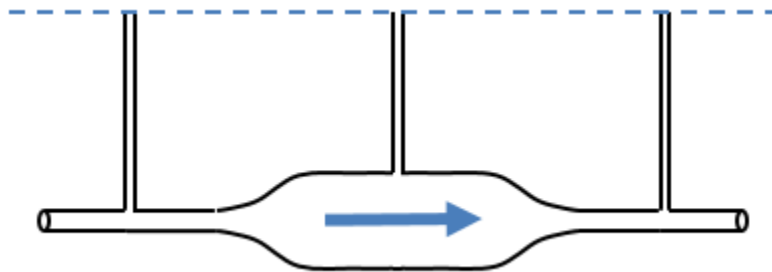


Figure 2. Sudden expansion and contraction in a pipe flow arrangement (arrow indicates the flow direction)

4.1 Methodology

The questions were developed based on common misconceptions among students in understanding fluid mechanics and heat transfer concepts. Additionally, we developed a range of questions based on various Bloom's levels; fewer questions at the lower Bloom's levels were developed because of previous findings that lectures prove sufficient for the types of information addressed at those levels [3, 26].

The key point in question development for the pre- and post-tests is to formulate questions that target concepts students would only understand better by using the hands-on learning devices. This is crucial to data analysis because in order to make the conclusion that growth between pre- and posttests is due to the LC-DLM, the questions on those tests must target concepts portrayed within the device.

A group of eight researchers from our group developed the new questions, four professors and four graduate students. The eight divided into equal groups to design questions for either the fluid mechanics or heat transfer concepts. Before testing the questions on undergraduate students, the whole group met to discuss the question inventories, and edited or eliminated questions upon

collective agreement. Because we planned to test these questions on students who have and have not taken the fluid mechanics and heat transfer course, we expected different results from the two groups. The students who have taken the course are better judges for the concepts tested, while the students who have not taken the course can better judge the comprehensibility of the questions.

After fine-tuning, the questions were tested using Qualtrics among a group of ten volunteer undergraduate students, six of whom had taken the fluid mechanics and heat transfer course and four of whom had not. The survey not only included the questions, but also included a Likert-type measure, in which students rated the clarity of the question on a scale of 1-10. After the question survey, the students were interviewed to further discuss the understandability of the questions.

To ensure that the survey and interview only took an hour of the student time, the 10 students were split into two groups, where the students who had and had not taken the fluid mechanics and heat transfer course were equally divided. The fluid mechanics survey included nine questions with the majority of the questions being newly developed; a portion of them were previously used as questions or modified from concept inventory questions. The heat transfer survey included 10 questions, a mix of new, reused, or concept inventory questions, where three of them included justification sections to reach a Bloom’s level of 5, evaluate.

5. Results and Discussion

5.1 Fluid Mechanics Survey

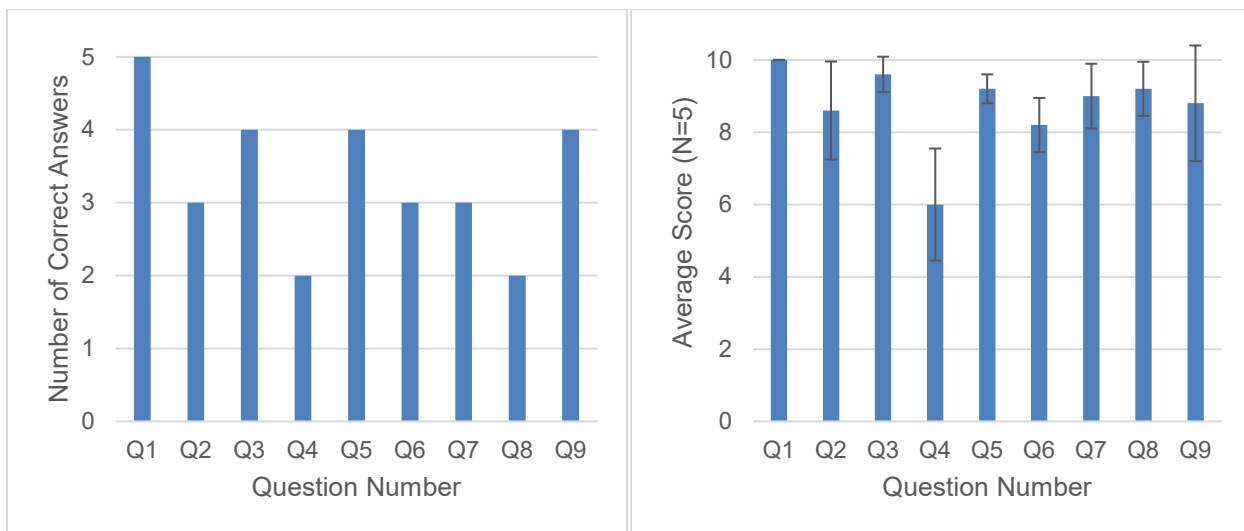


Figure 3. (a) Number of students out of five getting the correct answer; and (b) Likert-scale scores and standard deviations for the nine questions in the fluid mechanics survey.

Based on the number of students who chose the correct answer in Figure 3, the two major questions of concern are Q4 and Q8, energy transformation and visual head losses in an inverted venturi, respectively, as attention is needed on how to ask the questions or on the worksheet-guided instructions in particular for those who have already had the course. Additionally, students chose to comment on Q4 in the interview, stating that, “[you should] specify that the pipe is filled with fluid so you don’t think fluid is flowing downhill from [points] A to B,” and “[you] could just take

Point C out of the picture completely since [the] question isn't asking [about] it." This further explains why the Likert-scale score for Q4 is one of the two the lowest among all of the questions in this survey.

Based on previous interviews with professors conducted by a previous group member, students tend to struggle to grasp the concept of energy transformation in a venturi. Another point to note is that, because it is an inverted venturi, the question is focused on a scenario students have not encountered before and they must apply their current knowledge to a new system. These two points prove that these questions target a higher Bloom's level—Bloom's level 4, analyze, or level 5, evaluate, which may be why students struggled to answer such questions.

Other general comments from the student interviews included, “[you should] exaggerate [the] difference of fluid height in standpipes. [It is] sometimes difficult to see,” in regard to Q8, and “[you should] use equations instead of words when possible because they are easier to read.” The average amount of time to complete the survey was 10.3 minutes.

5.2 Heat Transfer Survey

Students struggled most in the heat transfer survey with Q7; they were asked which scenario out of three, where cross-sectional varies, would have the largest heat transfer rate. This may be due to lack of understanding of the relationship between fluid velocity and the thermal boundary layer.

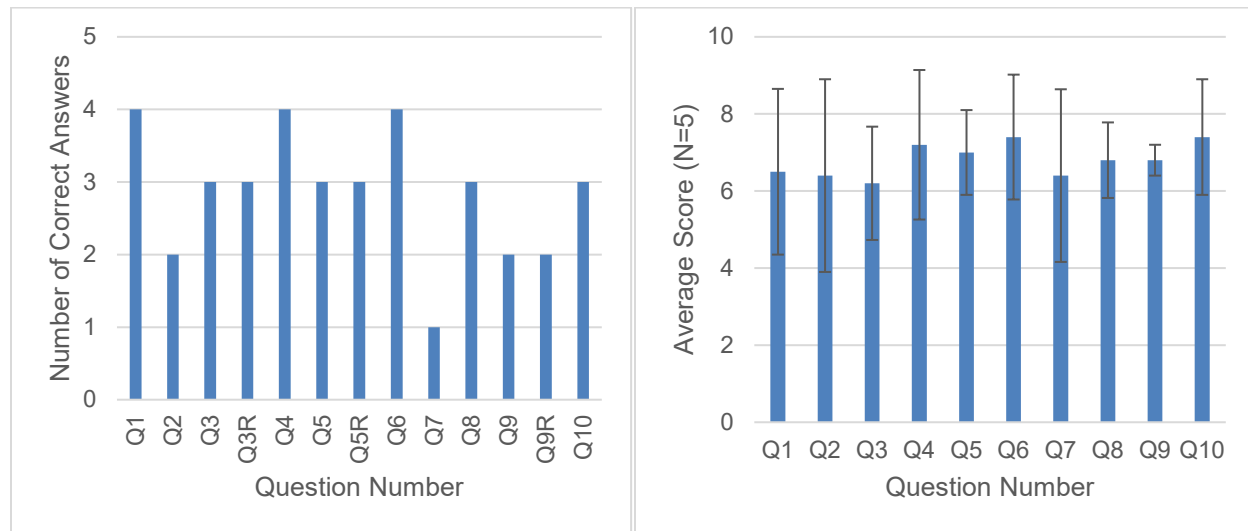


Figure 4. (a) Number of students getting the correct answer out of 5; and (b) Likert-scale scores and standard deviations for the 10 questions in the heat transfer survey. Question numbers followed by an “R” (e.g. Q3R) is the justification portion for the previous question.

General comments within this group heavily focused on the need for visuals. Popular comments were, “Coloring the tubes and shell different colors would be helpful,” in regard to Q4, “I think a picture would have been helpful,” from two students in regard to Q5, and that a picture would have been helpful for Q8, a statement from a student who had not yet taken the course. The interview with the students for the heat transfer survey may have centered on visuals much more than the

fluid mechanics survey due to the fact heat transfer is not something that can be seen without external measures.

The lack of visuals may also be the reason for lower ratings on the Likert scale on average, in comparison to the fluid mechanics results. The average time to complete this survey was 13.1 minutes, slightly higher than the average time for the fluid mechanics survey.

6. Conclusions

Achieving the goal of having a higher percentage of students thinking at the higher Bloom's levels is a focal point of our group's current efforts, as students show more significant growth for these types of questions when coupled with the LC-DLMs. The barrier previously, however, was the fact that the majority of higher Bloom's level questions, such as evaluate, take more time to answer; using a multiple-choice based reasoning question shortens this time. The surveys studied in this paper took 10-13 minutes on average to answer 9-10 questions, which is about the same amount of time used to answer our current pre- and posttests used in implementations that only include 4 questions, but with written justification aspects.

Overall, the efforts made during the production of this all-multiple-choice survey has allowed us to not only create multiple-choice questions that target higher Bloom's levels, but it also helped us better understand with what questions students struggle most and what additional steps can be taken to make questions clearer for them.

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