DEVELOPMENT OF A CONCEPT INVENTORY FOR FLUID MECHANICS

Jay Martin[1], John Mitchell[2], and Ty Newell[3]

Abstract *- Concept inventories are assessment tools designed to determine the degree to which students understand the concepts of a subject and to identify the misconceptions that students hold. The results of a concept inventory can be used to change the methods of instruction to overcome student misconceptions. A cooperative effort between Mechanical Engineering faculty at the Universities of Wisconsin-Madison and Illinois, Champaign-Urbana has been directed toward development of a Fluid Mechanics Concept Inventory (FMCI). Fluid mechanics typically follows thermodynamics in the sequence of courses in thermal sciences, involves both the mechanics and dynamics of fluids, and builds on basic physics and Newtonian mechanics. This paper describes the process used for development of the FMCI, the details of how we determined the content, and examples of actual content of the instrument itself.*

Index Terms – Concept inventories, Fluid Mechanics, Assessment

INTRODUCTION

Fluid mechanics is studied in many different disciplines. For example, in basic physics taught to freshmen and sophomores, a fluid is described, and pressure and density are defined. Hydrostatics is developed by taking into account the force on a static fluid element under the influence of gravity, followed by consideration of manometers and barometers. Fluid dynamics as introduced in basic physics includes conservation of momentum or the equation of continuity, Bernoulli's equation and ideas such as lift and thrust[1]. This is followed in many disciplines in engineering, and many of the natural sciences, with additional study of fluid mechanics.

Following the example of Hestenes and the Force Concept Inventory (FCI) [2], a cooperative effort of faculty at the University of Illinois, Champaign-Urbana and the University of Wisconsin-Madison has been aimed at development of a concept inventory in fluid mechanics. The Fluid Mechanics Concept Inventory or FMCI described here is aimed for use in assessment of Mechanical Engineering students who have or will be taking a course in fluid mechanics in Mechanical Engineering.

To begin the development, the first step was identification of the fluid mechanics concepts that were considered to be essential knowledge by Mechanical Engineering students having completed an undergraduate fluid mechanics course in Mechanical Engineering. The identification of concepts was initially done by experienced faculty and completed prior to writing individual questions. Once the concepts were identified, then multiple questions were written for each of the concepts, allowing for validation [3].

Following the lead of Kraus and other work on the development of a heat transfer concept inventory, students have been utilized in the development of the FMCI [4-5]. They were used in the identification of concepts and misconcepts, in the evaluation and development of questions used on the FMCI, and in the answers to the questions, assisting in the identification of key false positive answers (typically resulting from common misconceptions.)

IDENTIFICATION OF CONCEPTS

Identification of key concepts in fluid mechanics was, and is, considerably more difficult than would have been required for the Force Concept Inventory (FCI). Fluid mechanics, like other engineering subjects, does not have the same kind of readily identifiable model as the FCI, and is a combination of a large number of somewhat disparate concepts.

The list of concepts developed by the faculty is shown in Table I. Concepts identified begin with the basic concepts used in fluid mechanics, such as fluid properties and identification of boundaries and boundary effects. Concept identification places dimensional analysis and similarity in basic concepts. Fundamental fluid relations include conservation of mass and momentum. Specific terms in the equations defining conservation of mass and momentum were identified. Finally, there is a list of special topics that could be included in a FMCI depending on the discipline where the FMCI was used.

As shown in Table I, there are 3 principal areas that together comprise approximately 25 different concepts. This means that a concept inventory that had multiple questions on each of the concepts would be at least 50 questions, although it might be preferable to have 75 questions. An inventory of 75 questions is likely too long, and so it is possible that for any given application of the FMCI, a reduced set of questions will need to be used, or the number of concepts assessed will need to be reconsidered.

[1] Jay Martin, University of Wisconsin -Madison, Mechanical Engineering, 306 ME 1513 University Ave., Madison, WI 53706 martin@engr.wisc.edu
[2] John Mitchell, University of Wisconsin -Madison, mitchell@engr.wisc.edu
[3] Ty Newell, University of Illinois, Champaign -Urbana, t-newell@uiuc.edu

TABLE I

FLUID MECHANICS CONCEPTS TO BE ASSESSED. DETERMINED BY FACULTY EXPERIENCED IN TEACHING FLUID MECHANICS.

1. Basic Concepts
a. Properties
b. Boundaries
c. Dimensional analysis
d. Similarity
e. Laminar/turbulent flows
2. Fundamental Fluid Relations
a. Conservation of mass
i. Steady
ii. Unsteady
iii. Compressible
iv. Incompressible
b. Momentum (1= momentum terms, 2= pressure gradient terms, 3=gravity terms, 4=viscous terms)
i. Local and convective accelerations (term 1)
ii. Ideal (reversible) flow (variations of terms 1, 2, and 3)
1. Bernoulli flows (terms 1, 2, and 3)
2. Dynamic pressure (terms 1 and 2)
3. Momentum/reaction (terms 1 and 2)
4. Momentum flux and relative velocity (term 1)
5. Hydrostatics/manometry (terms 2 and 3)
iii. Viscous flow (variation of terms 1, 2, 3, and 4)
1. Pure viscous (term 4)
2. Low momentum, no gravity (terms 2 and 4)
3. All effects (various characterizations)
a) Parallel flow/boundary layer
b) Elliptical flow/separation and recirculation
3. Special Cases (areas of special interest to various fields)
a. Bluff bodies/separation (aero, civil, and mechanical)
b. Airfoils (aero and mechanical)
c. Pipe networks (civil, chemical, and mechanical)
d. Turbomachinery (aero and mechanical)
e. Compressible flow (aero and mechanical)
f. Channel flow (civil)

To further evaluate the validity of the concepts that experienced faculty identified, students that had completed fluid mechanics were asked to review the text used and notes they had written in the class. After their review, they were asked to write a list of the 10 concepts that they were certain of and that they felt were important and a list of 10 concepts that they were uncertain of and felt were not important. A comparison of the concepts identified by the students versus that of the faculty showed that the students identified some of the same concepts as the faculty as important. For example, students identified dimensional analysis, similarity, and laminar/turbulent concepts to be important. Students did not include fluid properties or boundaries as important. Students did not define specifics of conservation of mass. They did identify Bernoulli's equation as important. They felt comfortable with hydrostatics and manometry. They listed nearly all of the area specific concepts that the faculty included. Finally, the students listed a number of topics that were not on the faculty-generated concept list including pipe friction and conservation of energy.

Following the generation of the concept lists, the students were videotaped discussing both the lists they had generated and a set of questions developed by the faculty. For example, students were asked to describe the differences between laminar and turbulent flow and the differences between hydrostatic pressure, static pressure, stagnation pressure, and dynamic pressure.

CHALLENGES IN THE DEVELOPMENT OF CONCEPT INVENTORIES

There are a number of challenges faced in the development of concept inventories for engineering subjects. The first has been mentioned: in contrast to the FMCI, the FCI deals only with Newtonian Mechanics. The FCI does not attempt to assess all of the concepts developed in any physics course and is designed to assess student understanding only in the concepts associated with the model known as Newtonian mechanics. This differs from the objective of this concept inventory, as the FMCI is being designed to assess material covered in the study of fluid mechanics at the undergraduate level in Mechanical Engineering. There may be numerous models in the concepts that are part of the FMCI, which provides a challenge in determining the specifics of the content.

Second, engineering courses involve a complex interaction between understanding concepts and using those concepts in the solution of problems, oftentimes through the development of a set of skills. For example, the skill of being able to determine how fluid properties vary with temperature and pressure allows for the correct determination of mass and momentum transport. Without this skill, students would not be able to do analysis that would be useful in solving problems. It remains a significant issue as to how to assess student skills.

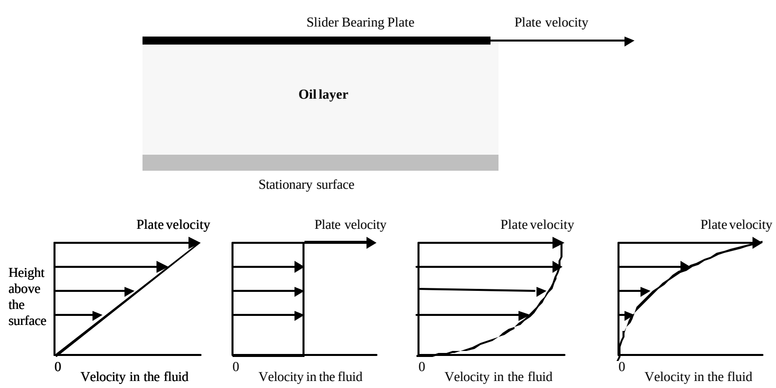
Third, student understanding of concepts is much different than faculty. As described, students have been used extensively to assist in the development of the FMCI. Another paper submitted for this conference describes, in detail, an assessment of the characteristics of the understanding of students of heat transfer (and fluid mechanics) [5]. While this information will not be repeated here, it is important to recognize the enormous difference in how students understand fluid mechanics and what instructors and professors are assuming (and hoping) that the students understand of the material. This difference should have a large impact on the characteristics of the concept inventory, if the concept inventory is to be useful in assessing student understanding. A couple of examples may be useful in describing this diffe rence further. For example, we have found that students do not use the same language as instructors use in describing their understanding. It is common for students to describe concepts in their own terms, which are different from the textbook descriptions of the concepts. If a concept inventory is to be useful at assessing student understanding, use of student-based descriptions of concepts might be necessary. A second example is students often miss subtleties that instructors' value as being particularly important to understanding. If the concept inventory is based on these subtleties, it will not be surprising that students will not do well.

DEVELOPMENT OF SPECIFIC QUESTIONS

Once key concepts were identified, questions were developed to explore student understanding of each of the concepts. A number of criteria were used in the development of the questions. For example, following the structure of the FCI, numerical calculation was avoided, and questions were developed that included graphic and visual representation of the concept being examined.

Shown in Fig. 1 is an example of a question developed to assess understanding of boundary layers. As illustrated in

The plate of a slider bearing moves at a steady speed over a layer of oil as shown in the figure below. The velocities in the oil are only due to the motion of the plate. Which of the curves best represents the velocity profile (distribution of the velocity of the oil with distance) inside the fluid?



a. b. c. d.

a. Profile a
b. Profile b
c. Profile c
d. Profile d

FIGURE 1
EXAMPLE PROBLEM ON BOUNDARY LAYER CONCEPTS.

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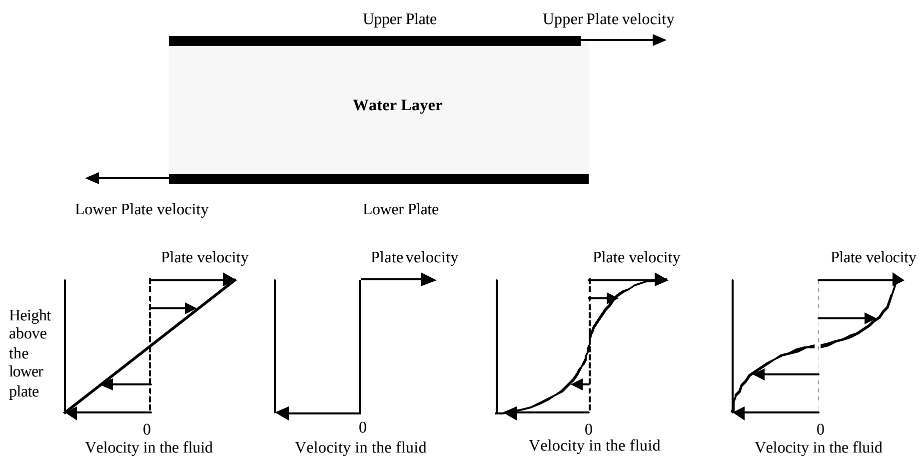
the figure, the focus of this problem is on an understanding of the no-slip condition at both the upper and lower surface. To answer this question according to the ideas of the writer, the assumption must be made that there are no pressure gradients in the streamwise direction driving the flow. Note also that there is no calculation or estimation required to do this problem.

The next example problem is illustrated in Fig. 2. This problem is slightly more complicated, because of the additional movement of the lower plate. To solve this problem correctly, the same concepts and assumptions necessary to solve the example problem shown in Fig. 1 are necessary.

Two plates are pulled in opposite directions as shown below. There is a layer of water between the two plates, and the only motion of the water is due to the motion of the plates. Which of the curves best represents the velocity profile (distribution of the velocity of the water with distance) inside the fluid?



a. b. c. d.

a. Profile a
b. Profile b
c. Profile c
d. Profile d

FIGURE 2
AN EXAMPLE OF A MORE COMPLEX PROBLEM IN BOUNDARY LAYER CONCEPTS.

The next example problem is presented in Fig. 3. As shown, this problem involves conservation of mass and Bernoulli's concepts. Assumptions necessary to apply this idealization are stated explicitly in the problem. This was done so that there would not be any ambiguity in interpretation of the problem. No calculation is necessary, although thinking of the relationship between velocity and flow area will be necessary for the students to determine the correct response.

Figure 4 shows an example problem involving jets and momentum transport. Again, assumptions necessary to solve this problem are given. In contrast to all of the other problems presented so far, there is a need to be able to assess the quantitative difference between the force F1 and force F2. Answers a,b, and c all involve an assessment in how much the momentum of the jet has been changed, and it requires that the students be able to understand how the final jet direction influences the force necessary to change the momentum. Answers d and e are there as distractors. These answers reflect what we believe would be common student misconceptions.

Finally, Fig. 5 is an example problem involving fluid acceleration. There are a number of differences in this type of problem versus the other problems that have been presented. First, the problem involves a combination of variables and units, allowing students to use units as a means of checking the answer, if they choose to do so. Second, the problem involves several different parts, each part focused on a different concept in fluid acceleration. If the students find the wrong answer in the first part, it is unlikely that they will get either of the other two parts correct. Finally, unlike the other problems, there will be algebraic manipulation required to determine the correct answers.

Water flows through a pipe and enters a pipe section (region "b") where the pipe cross-section area is smaller than the original area (region "a"). Viscosity and pipe friction effects can be neglected. Also, gravitational effects are negligible. Which of the following statements is true?

a) P_a is less than P_b and V_a is greater than V_b
b) P_a is less than P_b and V_a is less than V_b
c) P_a is greater than P_b and V_a is greater than V_b
d) P_a is greater than P_b and V_a is less than V_b

V_a = velocity in section a

V_b = velocity in section b

P_a = pressure in section a

P_b = pressure in section b

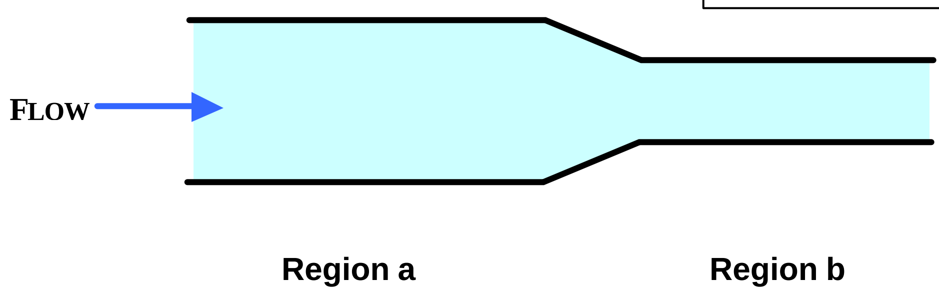


FIGURE 3
EXAMPLE OF A PROBLEM INVOLVING CONSERVATION OF MASS AND BERNOULLI'S CONCEPTS.

Two fluid jets are pointed at surfaces as shown in the figures below. The fluids are incompressible, and the effects of gravity can be neglected. The mass flow rate and the velocity of the jets are identical. The cross section area of the jets does not change significantly as the fluid flows. Which of the statements below is correct for the magnitude of the surface restraining force components shown in the figures?

a) $F_1 = 2F_2$
b) $F_1 > 0$, $F_2 = 0$
c) $F_1 = F_2/2$
d) $F_1 = 0$, $F_2 > 0$
e) $F_1 = F_2$

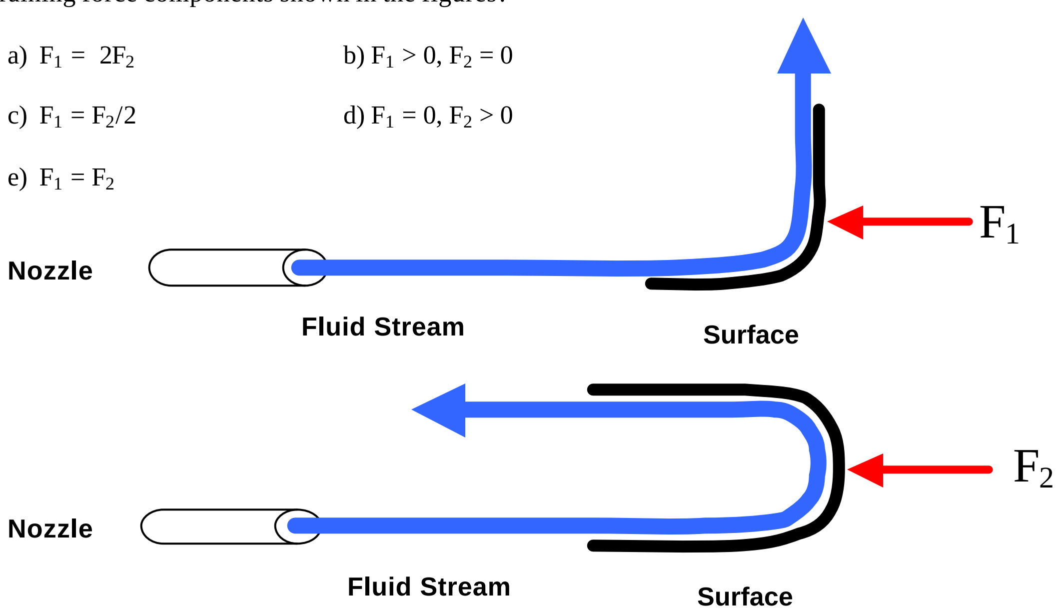
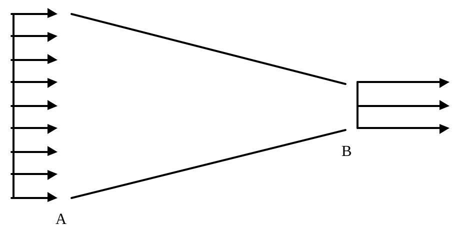


FIGURE 4
EXAMPLE PROBLEM IN CONSERVATION OF MOMENTUM.

A) Water at room temperature and pressure flows steadily through the nozzle shown in the figure below. At point A, the velocity is given as V_A m/s. The cross sectional area of the nozzle is square. At point A, the length of a side is a meters, and at point B, the length of a side is b meters. What is the volumetric flow rate at point B in m3/s?



a) V_A*a^2/b^2 m3/s
b) V_A*a^2 m3/s
c) V_A*a/b m3/s
d) V_A*b^2/a^2 m3/s

B) What is the acceleration at point B in m/s2? The distance from A to B along the centerline of the nozzle is c meters.

a) 0 m/s2
b) $V_B*((V_B-V_A)/c)$ m/s2
c) V_A*a/b m/s2
d) V_A/t m/s2

C) Suppose that the volumetric flowrate through the nozzle is now increased at the rate of d m3/s2. What is the acceleration of the fluid at point B now?

a) 0 m/s2
b) d m/s2
c) $V_B*((V_B-V_A)/c)+(d/b^2)$ m/s2
d) Cannot be determined from the information given
e) V_A/t m/s2

FIGURE 5
AN EXAMPLE PROBLEM IN FLUID ACCELERATION

SUMMARY

A cooperative effort between Mechanical Engineering faculty at the Universities of Wisconsin-Madison and Illinois, Champaign-Urbana has been directed toward development of a Fluid Mechanics Concept Inventory (FMCI). The process used to develop the FMCI included faculty input in the identification of key concepts. Then questions were developed to allow evaluation of student understanding of the key concepts. Students were also used in the development of the concept inventory, both in the identification of common misconceptions, and to assist in helping the developers' understand student perceptions of the technical content in fluid mechanics.

Development of good questions is complex for a subject like fluid mechanics because of both the number of concepts and the level of complexity of the answers. In the future, efforts will be focused on the development of a variety of concept questions, and the methods that these questions can be used in concept-based instruction.

ACKNOWLEDGMENT

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Note: Parties interested in the completed FMCI should contact one of the authors via email.