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Exploring a Virtual Reality Simulation to Aid Inductive Learning of Fluid Pressure Characteristics

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Exploring a virtual reality simulation to aid inductive learning of fluid pressure characteristics

Abstract

This paper introduces a desktop virtual reality (VR) simulation developed to facilitate inductive learning of fluid pressure characteristics and presents results from trialing it in inductive teaching (whole-class, teacher-led) vs. inductive learning (individual, more student-led) scenarios in a sophomore/junior level fluid mechanics course.

Assessments administered to gauge learning included true/false, descriptive and drawing questions. Results show that the inductive teaching scenario led to better student performance, with higher average scores across all but one question. These differences were significant for the whole assessment, and for the individual true/false questions. The inductive scenario used (as against gender, age, test scores etc.) turned out to be the only determining factor. The extent of differences between the two scenarios was substantial considering the introductory concepts addressed and the detailed guided inquiry materials provided.

The online and desktop version of the VR simulation are available for free use. Alternate versions (for tablets) and an augmented reality (AR) simulation that were developed for the same purpose are also mentioned.

Introduction

This paper introduces a desktop <u>virtual reality (VR) simulation</u> developed to facilitate <u>inductive</u> learning of fluid pressure characteristics and presents results from trialing it in an <u>inductive teaching vs. inductive learning</u> scenario in a sophomore/junior level fluid mechanics course.

Why inductive?
Inductive approaches are known to be better motivators of learning than deductive approaches. In a deductive approach, students are typically told the concepts they need to learn while in an inductive approach, students are made to uncover and construct these concepts through personal observation and inquiry. Inductive teaching and learning is in general more student centered and active, and expected to help retention. Extensive neurological and psychological research has shown that inductive methods encourage students to adopt a deep approach to learning and are in general more effective than deductive methods in achieving desired learning outcomes [1,2].

Why VR simulation?
Inductive approaches aim to facilitate interpretation based on observation and inquiry. And since making the unobservable observable, adapting reality to make chosen interpretations clearer and facilitating inquiry into multiple 'what if' scenarios are established strengths of virtual laboratories [3], VR simulations are well suited to aiding inductive approaches [4].

Why inductive teaching vs. inductive learning?
Inductive approaches and VR simulations are generally known to have positive effects on student learning [3,4]. However, the magnitudes of these effects vary based on how they are

implemented and used. For example, instructional setting, sequence and level of guidance provided are some of the factors known to affect the learning achieved while using inductive approaches or VR simulations [4-6]. Thus, work continues to be done to determine the best way of using these approaches and tools to maximize learning.

Educational tools, like the VR simulation in this case, can be used either as teaching tools or as learning tools. When the instructor interacts with the tool and uses it to 'teach', it acts as a teaching tool; when students interact with the tool themselves and use it to 'learn', it acts as a learning tool. When a tool is used as a teaching tool to teach concepts inductively, it results in an inductive teaching scenario; when students interact with the tool and use it as a learning tool to learn concepts inductively, it results in an inductive learning scenario. The purpose of this study is to evaluate the effectiveness of the VR simulation when used in inductive teaching vs. inductive learning scenarios.

Choice of concepts and inductive approach

This study required the development of a VR simulation that (a) aided inductive learning of fluid mechanics concepts and (b) was capable of being used as a teaching tool (in an inductive teaching scenario) as well as a learning tool (in an inductive learning scenario). Hence the fluid mechanics concepts to be covered and the inductive learning approach to be used had to be chosen so that the concepts could be learnt inductively by students just as easily as they could be taught inductively.

The two basic characteristics of forces exerted by fluids at rest are that (a) they are always perpendicular to the surface on which they act, and (b) they are constant over a horizontal surface and increase linearly in magnitude with depth. As these two characteristics are simple enough to be inferred from direct observation of distribution of forces, they were the concepts chosen to be inductively approached through the VR simulation.

Of the many inductive approaches spanning the spectrum from basic inquiry learning where students are presented with specific observations that they inquire into to answer specific questions, to discovery learning where students are left to discover concepts for themselves [2], basic inquiry learning was chosen for simplicity. A worksheet was developed with true/false, descriptive and drawing questions that could be used both to guide inquiry into the VR simulation and to assess the amount of learning achieved.

In essence this study involves:

(a) The development of a <u>VR simulation</u> that could be used to observe forces exerted by fluids at rest in order to inductively infer that such forces
  - (i) are always perpendicular to the surface on which they act,
  - (ii) are constant over a horizontal surface and increase linearly in magnitude with depth

(b) The <u>classroom trial</u> evaluating the effectiveness of the above VR simulation in an inductive teaching vs. learning scenario

It should be noted that inductive approaches can be seen within the context of inquiry based teaching/learning [2] and no distinction is made between the two terms here. Also, inductive teaching vs. inductive learning scenarios can be seen as two states on the continuum of guidance that differ in the level of guidance provided by the teacher [5] and as will become clear later, these scenarios can also be seen as comparing whole-class vs. individual use of simulations [4].

VR simulation

The VR simulation is a 3D desktop application, developed using the Unity 3D 5 game engine, depicting a transparent cuboidal tank that can be filled with water and an object immersed in it as shown in Figure 1. The application allows the user to (a) change the level of water in the tank, (b) choose one of two objects to immerse (with planar or curved surfaces), (c) toggle between showing and hiding the forces applied on the walls of the tank and on the surfaces of the immersed object, and (d) change the density of arrows used to depict the distribution of forces. Mouse and keyboard controls are used to adjust the viewing direction and distance, and to shift the point of focus to any point within the tank to examine objects and force distributions closely from any angle around the tank. The most recent version of the simulation is available at http://vel.engr.uga.edu/apps/VRFluidStaticsWeb/

Classroom trial

The VR simulation was trialed at the beginning of the spring 2016 semester in a required sophomore/junior level fluid mechanics course taught in the College of Engineering at the University of Georgia. Students in this course had completed the pre-requisite statics course with a grade of C or better and belonged to one of several engineering programs (Biochemical, Biological, Civil, Environmental and Mechanical Engineering).

The fluid mechanics course was taught in a flipped format with students required to (a) watch or read pre-class videos or textbook sections and complete an online pre-class assignment based on these videos/readings before coming to class, (b) solve problems assigned in-class, seeking help as needed from the instructor, undergraduate teaching assistants, and fellow classmates while in class, and (c) submit the completed in-class problems in the next class. The steps (a), (b) and (c) would then be repeated for the next class.

The first class of the spring 2016 semester involved a discussion of the course syllabus and expectations. The pre-class videos/readings, pre-class online assignment and in-class problems for the second class were on standard dimensions and units, dimensional homogeneity and general/restricted homogeneous equations. Neither the first nor the second class activities were related to stresses in fluids.

The VR trial spanned the pre-class and in-class activities for the third class of the semester; pre-class activities involved watching two videos, reading textbook sections and completing an online pre-class assignment; and in-class activities involved interacting with the VR simulation and completing a worksheet based on the concepts learnt through the simulation.

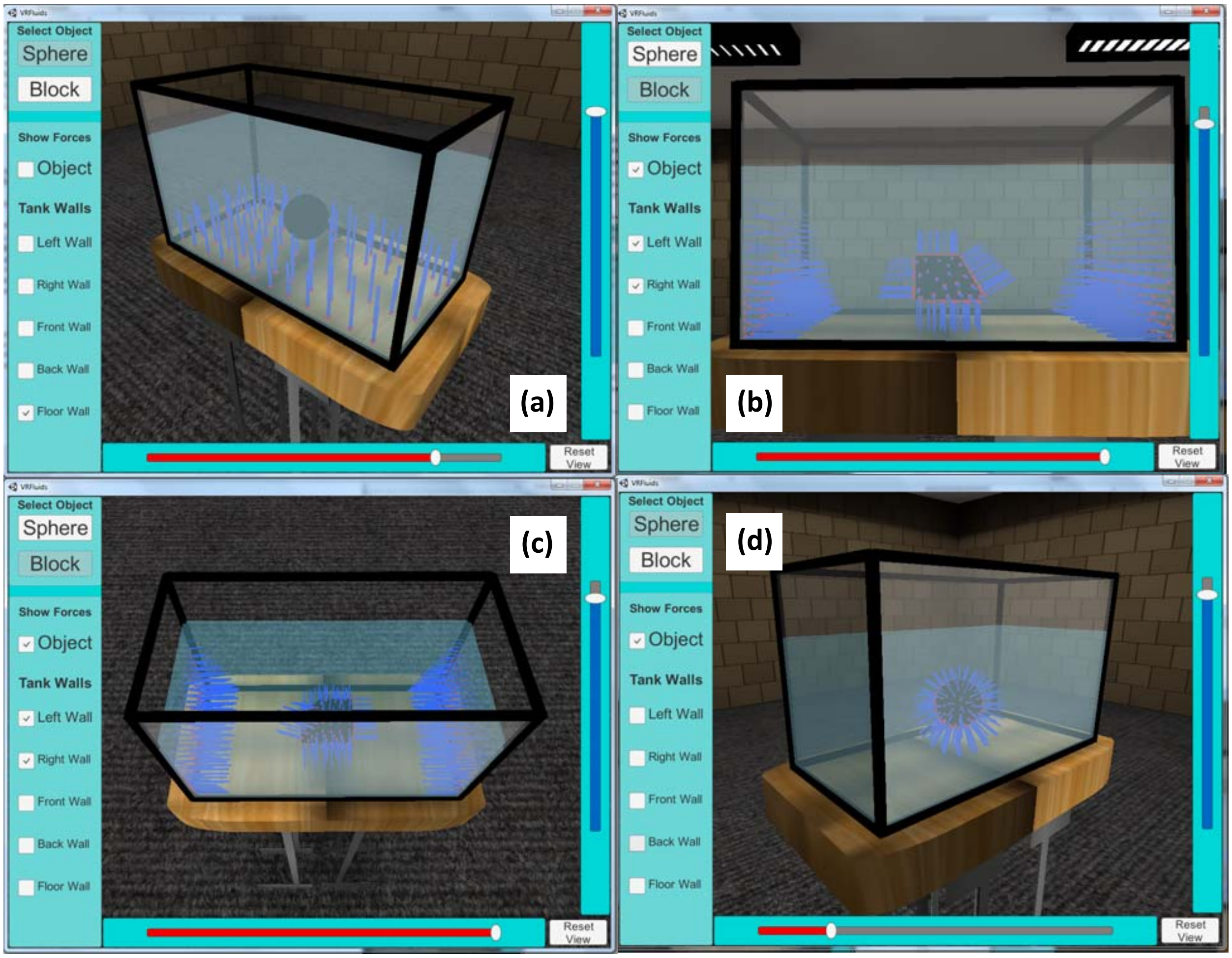

Figure 1. Views of the VR simulation with forces made visible on the: (a) floor of the tank; (b), (c) side walls and submerged block; and (d) submerged sphere. On the left panel are various options that can be chosen, at the right is the vertical slider that controls the level of water in the tank and at the bottom is the horizontal slider that controls arrow density. Pan/tilt/zoom are supported.

Pre-class videos

Two videos, *Introduction to Fluid Mechanics* and *Forces and Stresses*, were assigned as pre-class videos for the third class and all the concepts covered within them are shown in their screenshots on Figure 2. *Introduction to Fluid Mechanics* defined a 'fluid' in layman's terms (substance without definite shape of its own as opposed to solids), distinguished between liquids and gases (based on compressibility/density/specific weight) and stated only that a more precise definition of a fluid was based on stresses. *Forces and Stresses* recapped the distinction between concentrated and distributed forces (that students were taught in the pre-requisite statics course), defined stress as being the distribution of force over an area, distinguished between uniform/linear/non-linear distribution of stresses and introduced the fact that any stress over a surface can be viewed as a resultant of normal and shear stresses.

It should be noted that the above pre-class videos were designed to introduce kinds of stresses (normal and shear) and their distributions (uniform, linear and non-linear) *without* any reference to stresses or their distributions in fluids. Students were told that a precise definition of a fluid was based on stresses but they were never told what this definition was. The idea was to provide the context in which students could explore the VR simulation and *induce* by themselves the fact that fluids at rest do not have shear stresses and that the normal stresses are distributed uniformly on a horizontal surface and increase linearly with depth. This understanding was in turn used in subsequent classes to talk about fluids moving under shear stresses and led to the precise definition of a fluid as a 'substance that continually deforms under shear stresses'.

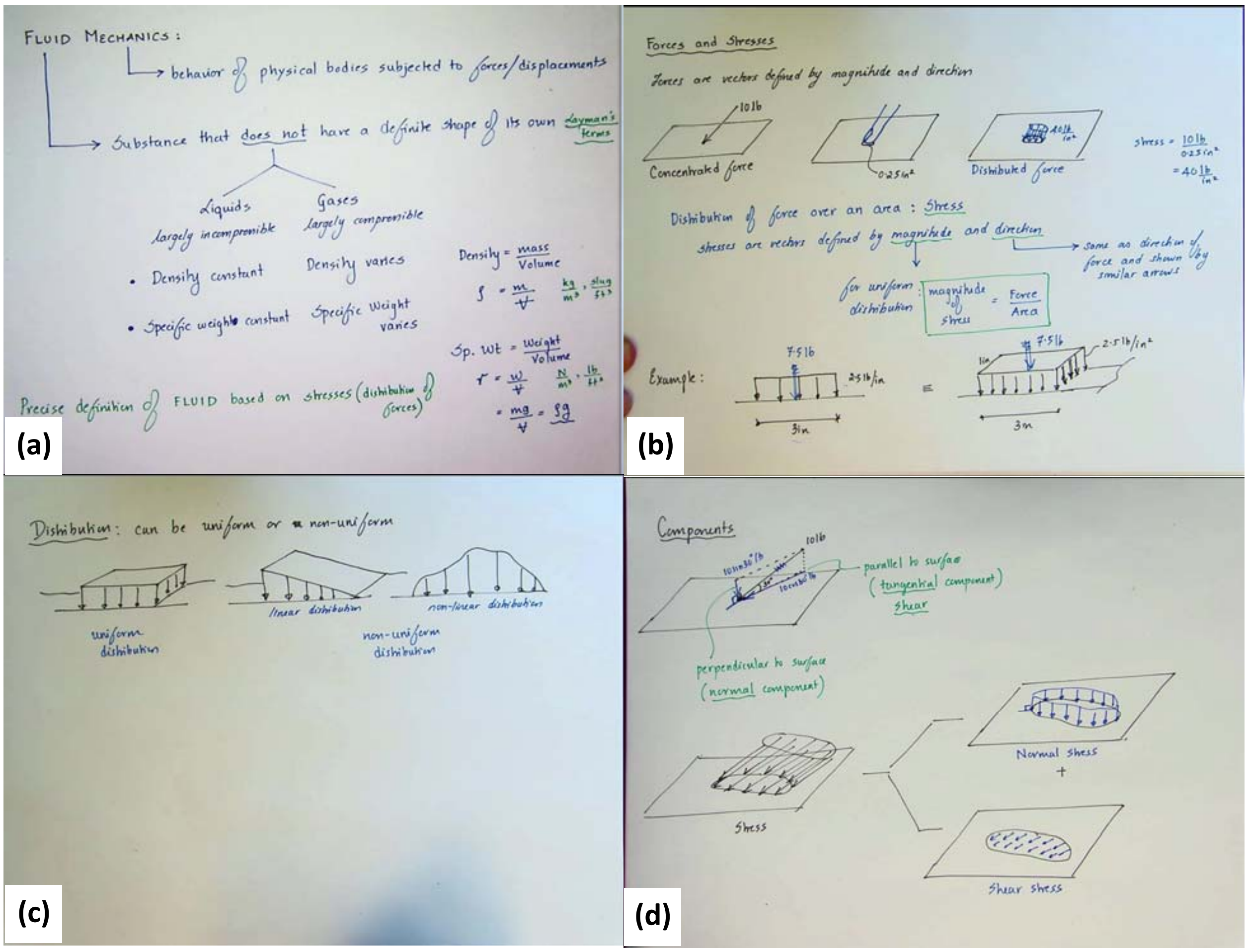

Figure 2. The two pre-class videos assigned to be watched before the classroom trial. (a) *Introduction to Fluid Mechanics*; (b), (c), (d) *Forces and Stresses.* The videos introduced general kinds of stresses and their distributions *without* any reference to stresses or their distributions in fluids.

Pre-class readings and online assignment

The pre-class readings for the third class of the semester included introductory readings from the textbook (Chapters 1 *Introduction* and 1.10 *A Brief Look Back in History* from [7]) and the pre-class online assignment was based solely on these readings. These readings and assignments had nothing to do with the VR trial and were part of the regular part of the course. They had no mention of distribution of stresses in fluids.

In-class VR simulation

The students enrolled in the fluids mechanics course were divided into two groups that met at two separate times for the third class of the semester. The division into groups was based on the time slot the students had signed up for, without any knowledge of what would be done in each of the groups. The first group had 29 students and the second one had 22 students. Note that both groups had gone through identical pre-class activities (introductory videos, readings and online assignment).

The first group of 29 students experienced the VR simulation as a teaching tool in an inductive teaching scenario. They were situated in a classroom without student computers. Only the instructor had access to the VR simulation and the instructor's interaction with the simulation could be seen by all students on the projection screen. The instructor explained that the simulation was about the stresses that a fluid at rest (water in a tank) applied on the surfaces it was in contact with and manipulated the VR controls while discussing the stress distributions seen on the screen. The students were prompted to identify the kind of stress (normal and shear) and the distribution (uniform, linear or non-linear) on the walls/floor of the tank and on the surfaces of the immersed object. Care was taken by the instructor to *not* specify these directly – recognizing the kinds and distribution of stresses had to come from the students. After this interaction, which lasted approximately 30 minutes, the students were asked to complete a worksheet based on what they had seen and discussed in the VR simulation. Students had to complete the worksheets individually and were *not* allowed to interact with the simulation or ask the instructor questions after they received the worksheet.

The second group of 22 students experienced the VR simulation as a learning tool in an inductive learning scenario. They were situated in a classroom with individual student computers that had the VR application available on them. Each student could individually manipulate and interact with their own VR simulation on their computers. The instructor explained that the simulation on each of their computers was about the stresses that a fluid at rest (water in a tank) applied on the surfaces it was in contact with and explained the VR controls available (pan/tilt/zoom, choice of submerged object, water level and arrow density). They were then advised to play with the simulation to understand what was happening and were asked to complete a worksheet (same worksheet as for first group). Students had to complete the worksheets individually but they had use of the simulation while they completed the worksheet (so that the questions on the worksheet provided the guided enquiry needed to explore the simulation). Similar to the first group, students could not get help from the instructor to answer the worksheet.

Worksheet

A worksheet was developed with statements/questions that could be used both (a) to assess student learning in the inductive teaching scenario, and (b) to aid guided inquiry while simultaneously assessing student learning in the inductive learning scenario.

The worksheet consisted of statements/questions categorized into 7 groups (Q1-Q7) as shown in Figure 3. Q1-Q5 consisted of 24 statements that needed to be identified as true/false with levels of confidence (total guess, low, moderate, high); these 5 groups were based on types of stresses (Q1), distribution of stresses on horizontal plane (Q2), distribution of stresses on vertical plane (Q3), distribution of stresses on inclined plane (Q4), and distribution of stresses on curved surfaces (Q5). The descriptive question (Q6) asked students to list the general principles regarding the type and distribution of stresses applied by fluids at rest. The drawing question (Q7) asked students to draw the fluid stress distribution on horizontal, vertical, inclined and curved surfaces on three tanks. Note that care was taken to restrict the terms and language in the worksheet to that introduced in the two pre-class videos.

Q1: Statements regarding **type of stresses** applied:

#	Statements	True/False	Level of confidence			
1	A fluid at rest applies *only* normal stresses on a surface of contact		0	1	2	3
2	A fluid at rest applies *only* shear stresses on a surface of contact		0	1	2	3
3	A fluid at rest applies *either* normal stresses *or* shear stresses on a surface of contact, but *never* both		0	1	2	3
4	A fluid at rest applies *both* normal stresses and shear stresses on a surface of contact		0	1	2	3

Q2: Statements regarding **distribution of stresses** on a **horizontal plane:**

#	Statements	True/False	Level of confidence			
1	A fluid at rest applies *uniformly distributed* stress on a horizontal plane		0	1	2	3
2	A fluid at rest applies a *linearly varying* stress on a horizontal plane and the intensity of stress *increases* from left to right		0	1	2	3
3	A fluid at rest applies a *linearly varying* stress on a horizontal plane and the intensity of stress *decreases* from left to right		0	1	2	3
4	A fluid at rest applies a *non-linearly varying* stress on a horizontal plane		0	1	2	3

Q3: Statements regarding **distribution of stresses** on a **vertical plane:**

#	Statements	True/False	Level of confidence			
1	A fluid at rest applies a *uniformly distributed* stress on a vertical plane		0	1	2	3
2	A fluid at rest applies a *linearly varying* stress on a vertical plane and the intensity of stress *increases* from top to bottom		0	1	2	3
3	A fluid at rest applies a *linearly varying* stress on a vertical plane and the intensity of stress *decreases* from top to bottom		0	1	2	3
4	A fluid at rest applies a *non-linearly varying* stress on a vertical plane		0	1	2	3

Q4: Statements regarding **distribution of stresses** on an **inclined plane:**

#	Statements	True/False	Level of confidence			
1	A fluid at rest applies a *uniformly distributed* stress on an inclined plane		0	1	2	3
2	A fluid at rest applies a *linearly varying* stress on an inclined plane and the intensity of stress *increases* from left to right		0	1	2	3
3	A fluid at rest applies a *linearly varying* stress on an inclined plane and the intensity of stress *decreases* from left to right		0	1	2	3
4	A fluid at rest applies a *linearly varying* stress on an inclined plane and the intensity of stress *increases* from top to bottom		0	1	2	3
5	A fluid at rest applies a *linearly varying* stress on an inclined plane and the intensity of stress *decreases* from top to bottom		0	1	2	3
6	A fluid at rest applies a *non-linearly varying* stress on an inclined plane		0	1	2	3

Q5: Statements regarding **distribution of stresses** on a **curved surface:**

#	Statements	True/False	Level of confidence			
1	A fluid at rest applies a *uniformly distributed* stress on a curved surface		0	1	2	3
2	A fluid at rest applies a *linearly varying* stress on a curved surface and the intensity of stress *increases* from left to right		0	1	2	3
3	A fluid at rest applies a *linearly varying* stress on a curved surface and the intensity of stress *decreases* from left to right		0	1	2	3
4	A fluid at rest applies a *linearly varying* stress on a curved surface and the intensity of stress *increases* from top to bottom		0	1	2	3
5	A fluid at rest applies a *linearly varying* stress on a curved surface and the intensity of stress *decreases* from top to bottom		0	1	2	3
6	A fluid at rest applies a *non-linearly varying* stress on a curved surface		0	1	2	3

Q6: *What general principles regarding the type of stress (normal or shear) and distribution of stresses (uniform, linearly varying or non-linearly varying) applied by a fluid at rest can be induced from your observations?*

Q7: *Draw the distribution of stresses as accurately as you can on the surfaces of contact shown below (the fluids they are in contact with are all at rest)*

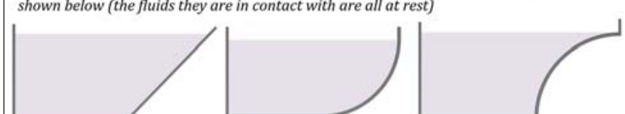

Figure 3. Worksheet questions categorized into 7 groups (Q1-Q7). Q1-Q5 have 24 true/false statements with four levels of confidence each (0-total guess, 1-low, 2-moderate, 3-high). Q6 is a descriptive question. Q7 requires drawing of stress distributions.

Data analysis and results

Data collected

Answers to all the worksheet questions (see Figure 3) and background data were collected for all participants (51) and analyzed for those that consented (50). Background data consisted of gender, age, major of study, years of post-secondary education, comfort level with drawing free body diagrams (6-point Likert), comfort level with using online applications (6-point Likert) and time spent playing video games (6-point scale from 0 to 16+ hours/week). Participants also completed a feedback/comments form that allowed them to specify whether the simulation had helped them answer questions on the worksheet (yes/somewhat/no), state what they liked/disliked about the simulation and provide other comments.

Participant scores in the three tests and final exam of the fluid mechanics course were also recorded. The three tests were held approximately 4, 9 and 12 weeks, and the final exam was held approximately 15 weeks after the classroom trial. The first test and the final exam had problems that used the concepts of pressure distribution in fluids at rest.

Scoring

Each of the 24 true/false questions in Q1-Q5 (see Figure 3) was scored on a 7-point scale from -3 to 3. A wrong choice of true/false made with high confidence received -3 (with moderate and low confidence receiving -2 and -1 respectively); a right *or* wrong choice for true/false made with no confidence (total guess) received 0; and a right choice for true/false made with high confidence received 3 (with low and moderate confidence receiving 1 and 2 respectively). The descriptive question Q6 was scored between 0 and 3 with one point awarded for mentioning each of the following: existence of normal stress only, uniform distribution of stress on a horizontal surface, and stresses increasing linearly with depth. Each of the 4 surfaces (horizontal, vertical, inclined and curved) in the drawing question Q7 was scored between 0 and 3 with 1 point awarded for showing each of the following correctly: type of stress (normal), magnitude of stress (uniform or linearly varying) and direction of stress (pointed towards the walls of the tank). Eventually all these scores were scaled to 0-100 to facilitate comparison with course test/exam scores.

Analysis

Of the 50 participants who consented, 29 (23M, 6F) experienced the simulation as a teaching tool in an inductive teaching scenario and 21 (16M, 5F) experienced it as a learning tool in an inductive learning scenario. Descriptive statistics are shown in following tables.

A first glance shows no significant difference in background data between the two groups (Table 1) but a statistically significant difference in true/false questions (Q1-Q5) and whole assessment (Q1-Q7) scores (Table 2). As shown in Figure 4, the inductive teaching group had higher average performance on 23 of the 24 true/false questions in Q1-Q5, on Q6 and Q7questions with many of these differences being statistically significant (Table 3). To determine the significance of this result, in context with other measured data and test scores, we used IBM SPSS 24 to conduct several analyses.

Table 1. Background data

		Age	Years post-sec ed.		Comfort free body diag.	Comfort online app.	Time playing video games
Inductive teaching	Mean	20.2	1.86		*U* = 228.5 *p* = 0.139 *Z* = 1.48	*U* = 265 *p* = 0.441 *Z* = 0.77	*U* = 300 *p* = 0.936 *Z* = -0.08
	Std. Dev.	1.24	0.915				
Inductive learning	Mean	20.9	1.95				
	Std. Dev.	2.49	0.805				
Significance *p*		0.247	0.713				

Note: t-test used for age and years of post-secondary education. Mann-Whitney U test used for comfort levels with free body diagrams, comfort levels with online applications and time spent playing video games

Table 2. Worksheet, test and final exam scores (as percentages)

		Q1-Q5	Q1-Q7	T01	T02	T03	Final
Inductive teaching	Mean	93.5	93.6	69.3	69.1	84.2	66.0
	Std. Dev.	8.26	6.74	14.0	18.3	9.08	17.8
	N	29	29	29	26	21	23
Inductive learning	Mean	83.1	83.1	80.0	74.1	86.5	69.4
	Std. Dev.	12.7	10.6	14.8	13.8	7.81	11.2
	N	21	21	21	20	19	19
Significance *p*		0.002**	0.000**	0.013*	0.294	0.398	0.456

** significant at 0.05 ** significant at 0.01*
N changes over the semester because of withdrawals/absences

Table 3. Worksheet scores (as percentages)

		Q1	Q2	Q3	Q4	Q5	Q6	Q7
Inductive teaching	Mean	93.2	97.1	93.8	91.0	92.5	93.1	94.3
	Std. Dev.	11.1	8.63	15.6	13.5	11.1	16.4	9.01
Inductive learning	Mean	82.5	90.9	79.6	87.3	75.0	74.6	92.0
	Std. Dev.	13.7	14.8	28.6	15.9	16.4	25.6	13.8
Significance *p*		0.006**	0.094	0.047*	0.393	0.000**	0.007**	0.518

** significant at 0.05 ** significant at 0.01*

Our primary analysis was a multivariate analysis of variance (MANOVA), using the condition (inductive teaching/learning) and gender as independent factors and the average of each question group as dependent variables. This analysis takes into consideration relationships between dependent variables in determining significance, which were expected, as an understanding of the concept should have an effect on all answers. Prior to this analysis, we excluded most background data as being insignificant and uncorrelated to results, however, we had found that gender had a substantial mean difference between male student performance and female student performance and was included as a second independent factor in our analysis.

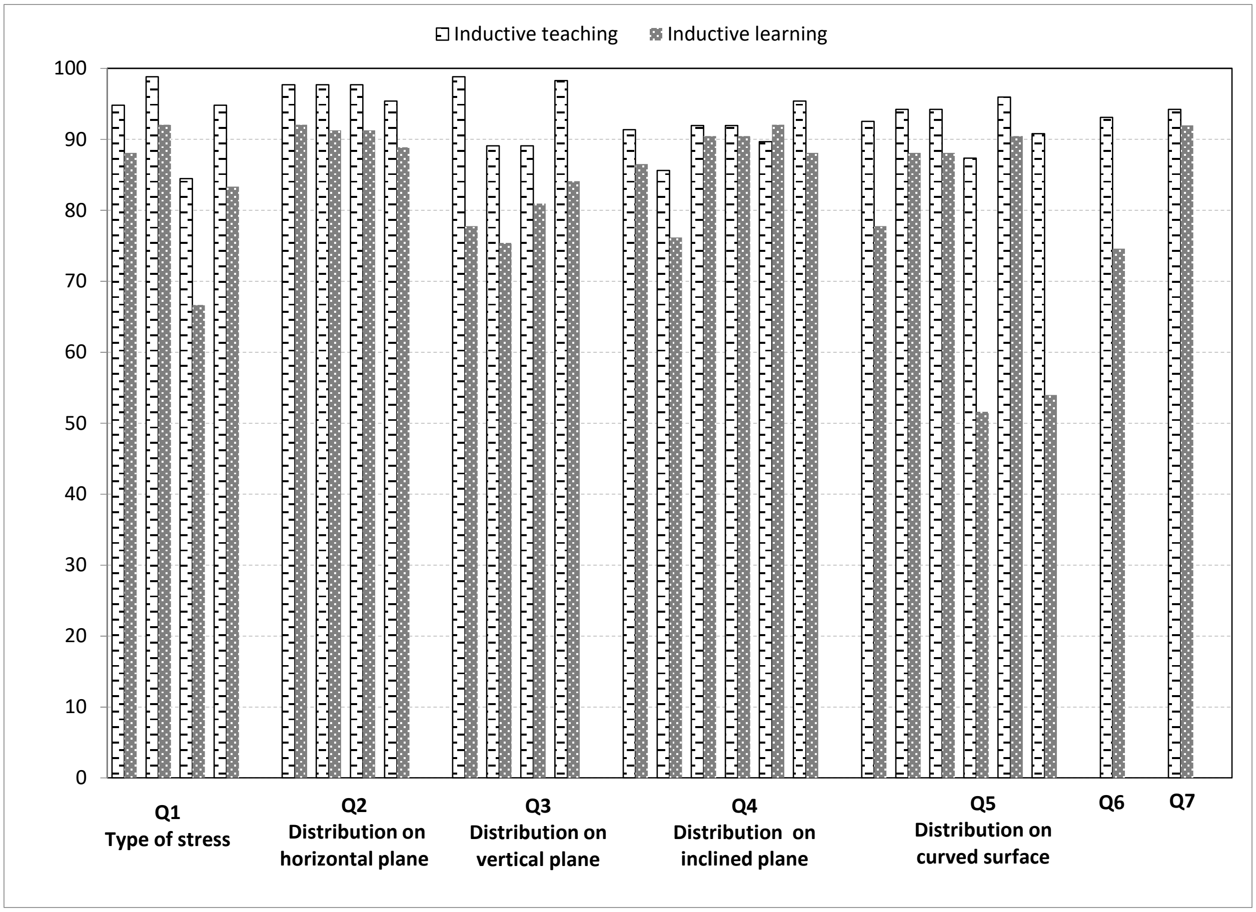

Figure 4. Averages of the 24 true/false (with confidence level) questions grouped into 5 categories (Q1-Q5), Q6 and Q7 expressed as percentages

Results from the analysis showed significant effects of condition ($F(7,40) = 3.679$, $p<0.005$), and gender ($F(7,4) = 5.714$, $p<0.001$). In post-hoc testing of individual question groups, Q1, Q2, Q3, Q5 and Q6 were significant for condition, and Q2, Q4 and Q7 were significant for gender. The interaction effect for gender and condition was not found to be a significant factor ($F(7,40) = 2.092$).

Participant comments indicated appreciation of 3D visualization, and overall ease of use and interactivity. Suggestions included addition of more submersible objects with varied shapes, ability to move submerged objects in the tank and ability to depict fluid motion (e.g. by 'kicking' the tank) to see whether shear stresses would be developed. Requests were also made to consider developing such applications for other courses.

Discussion

It is clear from the data that the inductive teaching scenario, for most students, was superior to the inductive learning scenario as far as performance on the assessment (Q1-Q7 in Figure 3) was concerned.

At first glance, one might argue that the above result is wholly expected because the inductive learning scenario places students at a disadvantage by leaning more towards discovery learning that requires substantial self-direction, while students in the inductive teaching scenario have the advantage of instructor guided inquiry [4-6]. It should be noted however that these factors were explicitly considered while deciding on the concepts to be targeted and the questions that were to be posed in the worksheet. The concepts targeted, namely the nature and variation of forces exerted by fluids at rest, were felt to be simple enough to be recognized when they were observed in the VR simulation and the worksheet questions were explicitly designed to guide students in their inquiry. Moreover, students in the inductive teaching scenario did not have access to the worksheet questions until after the 'teaching' was completed and they did not have access to the VR simulation while they were completing the worksheet; in contrast, students in the inductive learning scenario had access to both the worksheet and VR simulation simultaneously and they could use the worksheet questions to guide their inquiry into the simulation.

A deeper look at the data yields some interesting results. The effect of better performance in the inductive teaching scenario was most pronounced on true/false type questions (Q1-Q5) and descriptive question (Q6), and notably not significant for the drawing question (Q7). Interestingly, the drawing question had very high performance for *both* scenarios, with the highest average observed for this question relative to all other questions. This could imply that, while most students had an intuitive visual understanding of the stresses (not surprising since the simulation was entirely visual), the students in the inductive learning scenario were less able to explain their understanding. A possible explanation for this could be that students in the inductive teaching scenario were specifically instructed to think about the explanations, but students in the inductive learning scenario were not (though this was part of the guided inquiry). In addition, the need to manipulate the interface could have placed an additional cognitive load on students in the inductive learning scenario and teacher guidance is known to reduce cognitive load [4,6]. Moreover there is the social dimension of whole-class interaction in the inductive teaching scenario that is known to generally improve learning [5].

We also found a significant effect of gender, which had a notably different effect. Whereas scenario was a not a significant factor in the drawing question Q7, gender was found to be a significant factor. Male students performed significantly better (95%) than female students (87%). Better performance for male students was consistent for all questions except the descriptive question Q6. Note that drawing substantial conclusions from these is difficult because of the low number of female students in the analysis (11F, 39M). However, we were encouraged that gender did not have a significant cross effect with scenario, i.e. gender is not likely to be a significant factor in choosing one inductive scenario over another. We considered that gender and game playing may be related, finding a trend ($p<0.1$) in an ANOVA. However, game playing was not a found to be a significant factor in the previous analyses and was excluded.

We considered that there may have been base-level differences between the two groups. To test this, we analyzed the mid-term exam scores of all students throughout the semester and the final exam. By strong contrast to the assessment, participants in the inductive learning group fared significantly *better* on the first exam (T01) following the assessment than the inductive teaching group (see Table 2) – so base-level difference between the groups is unlikely to be a reason for the better performance of the inductive teaching group in the assessment. The difference in exam performance was gradually reduced over the remaining course tests and final exam (Table 2). Thus, we can be confident that the inductive learning group (which fared poorly in the trial) was not eventually negatively affected by the trial, and that a priori understanding of the concepts was unlikely to be higher. Note that all students (from both trial groups) received the regular instruction on pressure distribution in fluids at rest in the class following the trial to ensure that everyone was brought up to speed and any difference in learning that occurred because of difference between the treatment of the two groups was corrected. We also note that no significant relationships were found between assignment scores (or any question group) and exam scores.

Alternate versions

Alternate versions of the application were developed as part of an iterative process to determine the interface for the application, but were not used in this study. A brief overview/discussion follows for users interested in exploring their use in their classrooms.

AR Simulation

Originally an Augmented Reality (AR) application was built for this study but robustness concerns forced us to shelve it and develop the VR application instead. The AR system is shown in Figure 5. The AR interface is similar to the VR interface but it interacts with the physical tank of water (with a physical submerged object) and augments the physical view with the distribution of forces on various surfaces. The water level in the physical tank can be automatically raised/lowered through a pump controlled by the AR interface and the augmented force view changes correspondingly. The submerged object however has to be manually switched. The user can move around the physical system to view it from different angles.

Tablet VR simulation

Two other versions of the VR application were developed for tablets with multi touch gestures (iPad Air 2) and mobile tracked display (iPad Air 2 with Occipital Structure Sensor). The primary difference between these versions was locomotion technique – one version used multi touch gestures to change the view in the simulation (pan/tilt/zoom) while the other required physical movement of the tablet around a virtual tank to do the same. These two tablet VR simulations were trialed on two groups of students in a statics course and the discussion/results can be found in [8].

Conclusions

Students experiencing a VR simulation in an inductive teaching scenario (whole-class, teacher-led) performed significantly better on assessments than those experiencing it in an inductive learning scenario (individual, more student-led with guided enquiry). The extent of performance difference between the scenarios was substantial considering the simplicity of concepts addressed (nature and variation of forces exerted by fluids at rest) and the detail of guided inquiry provided through the worksheet. Nevertheless, this result matches prior findings in literature that show increasing guidance and including social dimensions leads to improved learning [4-6].

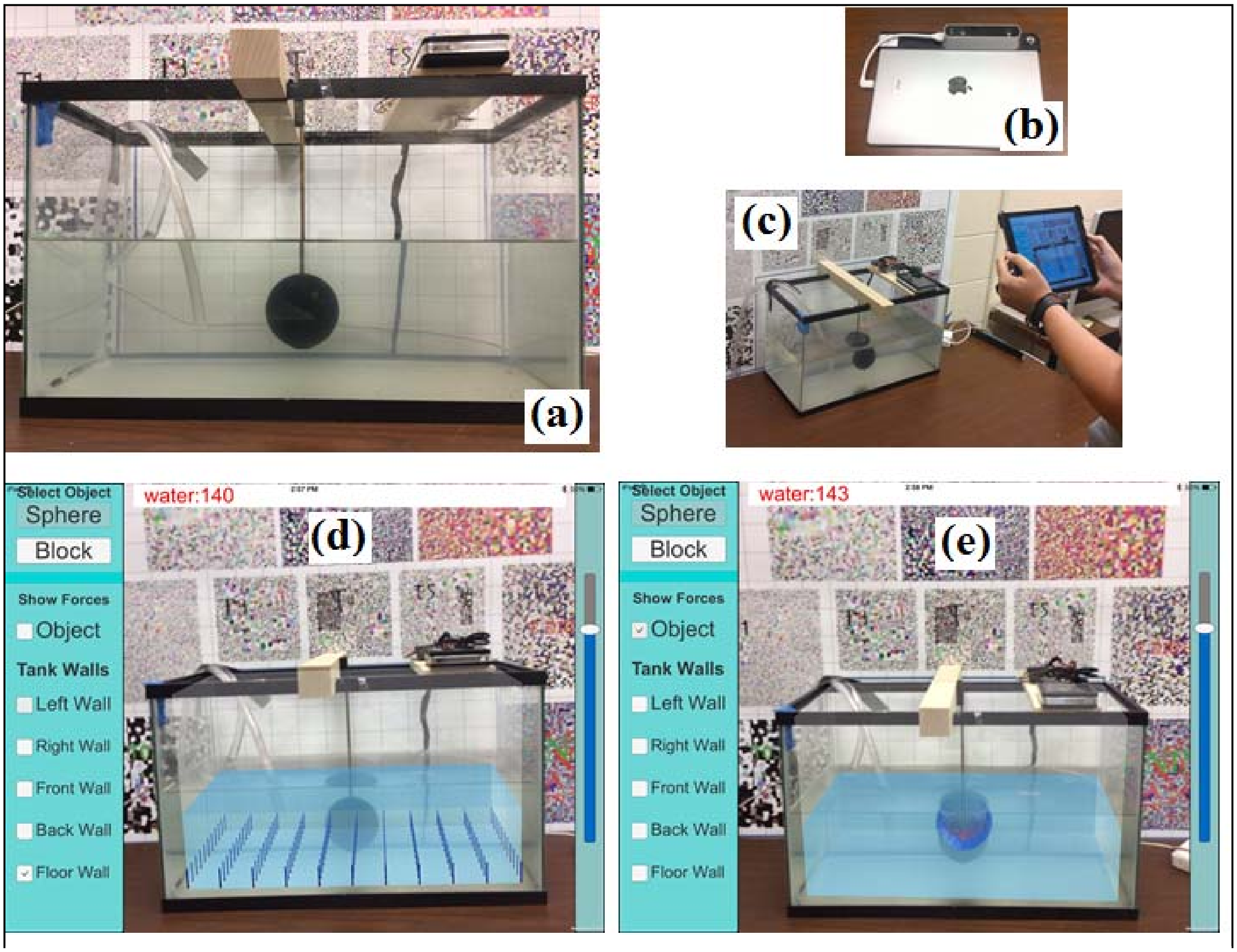

Figure 5. Views of the AR simulation: (a) Physical system consisting of a container of water with a submerged sphere; (b) iPad with the AR application used to view the physical system; (c) a student viewing the physical system through the AR application on the iPad; (d) augmented view of the physical system with forces on the floor of the container made visible; (e) augmented view with forces on the curved surfaces of the submerged sphere made visible.

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