Exploring Student Difficulties with Pressure in a Fluid

Matthew Goszewski, Adam Moyer, Zachary Bazan, and DJ Wagner

Grove City College, 100 Campus Drive, Grove City, PA 16127

Abstract. Our research group is developing a standardized fluids assessment, covering buoyancy and pressure. Much of the prior research of student difficulties with pressure involves young children. Many of the questions on the beta-version of the assessment used this past year were designed to test the prevalence of those difficulties in college students. In this paper we will describe several pressure-related assessment questions, the misconceptions they probe, and the preliminary results from the beta version of the assessment.

Keywords: Pressure, Fluids, Education Research.
PACS: 01.40.Fk, 01.40.G-

INTRODUCTION

As part of the development of a fluids statics diagnostic, we are examining student conceptions of pressure in a liquid. We identified many conceptions through interviews and analysis of long-answer questions, but we also have drawn distractors for our questions from studies by others [1-9]. Since only [1] and [2] involve college students, and very few [3-5] of the others even involve students above the age of 15, we wondered which of the difficulties identified in those papers would be significant in college courses.

Drafts of our diagnostic have been given to three introductory courses at Grove City College: a calculus-based course ("calc"), a trig-based course ("trig"), and a concept-based course ("cnpt").

This paper concentrates on four of our pressure questions which explicitly address student conceptions identified by other studies. We first review several student ideas about static pressure in liquids, and then we summarize their prevalence in our three introductory courses as measured by those questions.

WORK BY OTHERS

Perhaps the most commonly identified student difficulty [3-7] with pressure is making a distinction between "vertical" and "horizontal" pressure. We have labeled this conception as "**direction**." In this context, many students believe horizontal pressure is proportional to the distance from the container's edge [5,6]. Thus, as you move toward or away from a wall, the (horizontal) pressure changes ("**distance from wall**"). Other students may adhere to a "confinement" [1], or "packed crowd" [7], model, where a narrower container or enclosed region would cause a higher pressure [2,7,8] ("**enclosed**"). Similarly, students may say that an object floating above a point could increase pressure [9].

Students often misinterpret h in the equation for pressure: $P = P_0 + \rho gh$. Students might identify h as the horizontal distance to a wall or to a boundary directly above the point [1,2] ("***h* mistake**"), or the distance along a tube from its opening [1] ("**distance from opening**"). The study of reference [4] identified the belief that pressure was higher at the top of a liquid, since it is applied from the surface.

Other ideas about pressure include pressure being determined by the amount of fluid above a point [1-3], or by the volume of fluid around the point [4,7,8] ("**amount above**").

Students can fail to distinguish density and pressure [1]. This lack of distinction is one of several explanations of why students say pressure has the same value throughout a liquid [1,2,4,7] ("**uniform"**).

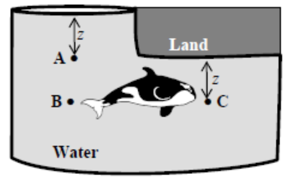
OUR QUESTIONS

This paper will discuss results from four questions on our diagnostic exam draft: "Shamu," "3-shape," "Larger P," and "Balloon P" [11]. Figure 1 contains the full text of the questions. Table 1 lists the conceptions associated with question options.

In the Shamu question, option *A* might be chosen by students who think horizontal **distance to a wall** determines pressure. (The * in Table 1 indicates the non-exact mapping of the conception to the answer.) Option *B* probably indicates an ***h* mistake**, with *h* measured to the surface directly above. Option *D* indicates **uniform** pressure. Option *E* indicates that pressure depends upon something more than depth alone, including the **amount above** conception.

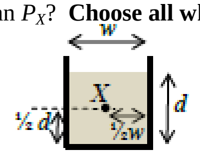
The 3-shape question overlaps the Shamu question; we included explanations since our preliminary studies

"**Shamu**": Killer whale Shamu is floating at rest in his glass-walled aquarium, a cross-section of which is shown to the right. (The right half of the aquarium is underground.) Three points in the aquarium are labeled; B and C are at the same level and can be connected by a horizontal line, and point A is the same distance *z* below the surface as B is below the wall above it. At which points is the pressure the same?

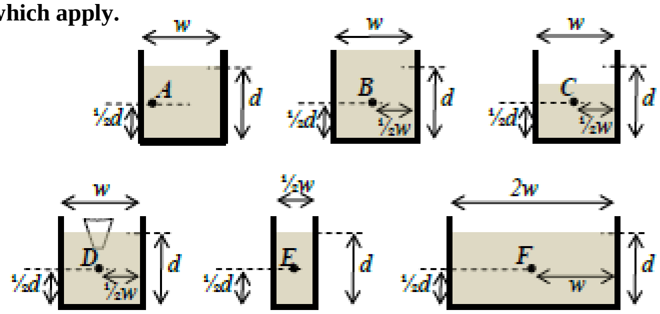


A. The pressure at A is the same as the pressure at B.
B. The pressure at A is the same as the pressure at C.
C. <u>The pressure at B is the same as the pressure at C</u>.
D. The pressure at all three points is the same.
E. No two labeled points have the same pressure.

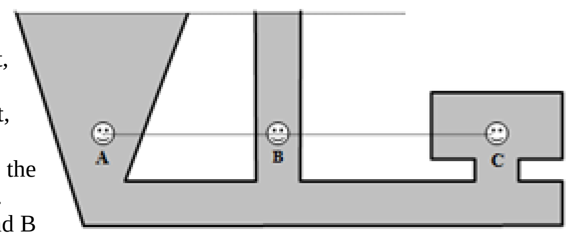
"**Larger P":** Consider point *X* at the mid-point of a beaker of water of width *w* and water depth *d*, as shown to the left below. The pressure at *X* is measured and found to have a certain value P_X. Which of the labeled points *A-E* in the situations depicted below will have a pressure larger than P_X? **Choose all which apply.**



A. Point *A*, which is closer to the wall than *X*.
B. <u>Point B, which has more water in its container</u>.
C. Point C, which has less water in its container
D. Point D, which is under a floating object.
E. Point E, which is in a narrower container.
F. Point F, which is in a wider container.
G. None have pressure larger than P_X.



"**3-Shape**" [11]: In the diagram to the right(above), a container of water is filled to the brim, open to the air above points A and B but closed above point C. How do the water pressures compare at points A, B and C, all of which can be connected by a horizontal line?



A. The pressure at B is highest, and the pressure at C is the lowest, because B is closest to the container walls.
B. The pressure at A is highest, and the pressure at C is the lowest, because A has the most water above it.
C. The pressure at C is highest because it's enclosed. Point B has the lowest pressure, because it has less water above it than A does.
D. The pressure at C is highest because it's enclosed. Points A and B have the same (lower) pressure, because they are in open sections and at the same level.
E. <u>All three pressures are the same, because all three points are at the same level</u>.
F. The pressure at A and B are the same, but that pressure is higher than the pressure at C. Pressure is determined by the distance to the top of the container, and the top in point's C section is lower than the top in A and B.
G. The pressure at C is the greatest, and the pressure at A is the smallest, because pressure increases as you get further from the initial opening of the container.

"**Balloon P**" [11]: An air-filled, roughly circular, balloon is tied to a rock and placed at the bottom of a swimming pool. Compare the balloon at the bottom of the pool to the balloon before it was placed in the water.

A. <u>The balloon at the bottom of the pool is smaller but still roughly circular</u>.
B. The balloon at the bottom of the pool is larger but still roughly circular.
C. The balloon at the bottom of the pool has been flattened into a pancake shape.
D. The balloon at the bottom of the pool has been squished into a tall, narrow column.
E. The balloon at the bottom of the pool will burst.
F. The balloon at the bottom of the pool is the same shape and size as the balloon out of the pool.

FIGURE 1. The four pressure questions considered in this paper. Underlined answers are correct.

TABLE 1. Conceptions Discussed in Paper and Associated Question Items (*not explicit map of concept and answer)

	Enclosure	***h* mistake**	**Amt Above**	**Dist wall**	**Dist opening**	**Direc.**	**uniform**
Shamu Options	-	*B*	*E**	*A**	-	-	*D*
Larger P Options	*D**	*C*	*F*	*A,E*	-	-	-
3-Shape Options	*C,D*	*F*	*B,C*	*A*	*G*	-	-
Balloon P Options	-	-	-	-	-	*C,D*	-

using the "N-tube" question of reference [1] found that students could choose the same rankings for different reasons.

Our Larger P question lets students choose all factors which they think influence pressure. Thus the percentages of students choosing each option for this question add up to more than 100%.

The Balloon P question explores the prevalence of pressure having preferred **direction**. Options *C* and *D* each imply that pressure is direction-dependent. Options *B* and *E* imply that pressure decreases under water, and option *F* implies that pressure under water is the same as out of water.

RESULTS

The diagnostic was administered in both the first and last weeks of workshop to all three classes in fall, 2011 (F11), and to the conceptual class in spring, 2012 (S12). Since this paper's purpose is to identify the presence or prevalence of different conceptions in various populations, rather than to measure the effect of instruction, we include all available data rather than removing the handful of unmatched pre/post tests.

***h* mistake.** The Shamu question proved somewhat easier than the 3-shape question, as shown in Table 2. The 3-shape question included explicit reasonings, which seems to have affected the choice of specific incorrect answers. In the Shamu question pre-instruction, over 24% of students in all three classes chose *B*, claiming that the pressure is determined by the distance to the top of the container directly above the points. In the 3-shape question, however, 10% or fewer of the students chose the corresponding option *F*. Post-instruction, calc and trig students, which use activities based on the Pressure *Tutorial* [10], were very unlikely to choose this option. Conceptual students, who spend no workshop time on pressure, did choose the "*h* mistake" options after instruction, particularly for the Shamu question (28% and 34%). Additionally, a significant portion (8% and 16%) of post-instruction conceptual students chose *C* in Larger P, where *h* could be measured from the bottom.

Amount above. Students were more likely on the 3-shape question than the Shamu question to choose one of the options based on an amount above argument. Since the 3-shape question explicitly provides the justification, and the corresponding Shamu option (*E*) has the feel of "none of the above," this difference is perhaps not surprising. As with the "*h* mistake" conception, the "amount above" conception is chosen by few trig and calc students post-instruction but is popular with post-instruction conceptual students.

Enclosed. Enclosure was very popular with our students. Options *C* and *D* in the 3-shape question were chosen by one third to one half of students pre-instruction (see Table 3). Explanations provided by students include, "Because C is enclosed, it has pressure from the entire container acting upon it, thus giving it the greatest pressure," and "C is under more pressure because it is closer to more surfaces."

Large P lacks an explicit "enclosed" option, but a floating object (option *D*) gives a similar effect. Between 10-25% of students chose that option pre-instruction. The "enclosed" conception seems to be one of the most popular wrong answers post-instruction, particularly with the calc and trig students.

Distance to walls. We also considered whether students think pressure increases near walls (*A* in Large P and Shamu) and in narrow containers (*E* in

TABLE 2. Percent choosing various conceptions on Shamu vs. 3-shape questions.

Course & Sem	***n***	**Correct Answer**				***h* mistake**				**Amount above**			
		Shamu *C*		**3-shape *E***		**Shamu *B***		**3-shape *F***		**Shamu *E***		**3-Shape *B*+*C***	
	Pre/Post	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Calc F11	157/147	50	93	27	85	24	3	**8**	3	17	1	40	5
Trig F11	75/71	40	94	12	76	32	3	9	7	24	1	29	9
Cnpt F11	102/100	38	47	11	37	26	28	10	18	26	3	35	22
Cnpt S12	79/79	34	42	3	33	25	34	3	8	22	16	51	42

TABLE 3. Percent choosing various conceptions on Large P vs. 3-shape questions. Since Large P was multiple-select, totals add to greater than 100%. The % correct is the % choosing only *B*, not the % including *B* in the answer.

Course & Sem	***n***	**Correct Answer**				**Enclosure**				**Distance to wall**			
		Large P *B*		**3-shape *E***		**Large P *D***		**3-shape *C*+*D***		**Large P *A*+*E***		**3-Shape *A***	
	Pre/Post	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Calc F11	157/147	34	54	27	85	13	6	36	6	22	9	5	1
Trig F11	75/71	25	49	12	76	20	8	42	14	40	7	4	0
Cnpt F11	102/100	17	38	11	37	25	14	36	26	30	23	4	3
Cnpt S12	79/79	25	23	3	33	25	14	52	26	34	30	9	4

Large P). Option *A* in the 3-shape combines these ideas, since the container is narrow but the explanation explicitly mentions the closeness to walls. This option is not very popular in 3-shape or in Shamu, where students must select a single answer, but it is prevalent in the multiple-select Large P. (Shamu *A* percentages are similar to 3-Shape *A* percentages.)

Direction. The balloon question examined the directionality of pressure. It was not included in the pre-instruction F11 test. Post-instruction, between 41% (conceptual S12) and 72% (trig) of the students answered correctly that all dimensions would shrink. Interestingly, the most common incorrect choice (although probably not statistically significantly different from the other incorrect choices) was that the balloon would burst, perhaps suggesting a preferred outward direction for pressing forces.

Between 4-15% of students indicated that a balloon at the bottom of the pool would be tall and narrow (option *D*), while a similar number said that the balloon would have a pancake shape (option *C*). Thus up to 30% of post-instruction students attributed directional behavior to pressure. Another question on the diagnostic gave students the option to say pressure at a vertical surface is zero; only 1-3% of students chose that option, even pre-instruction. Our students do treat directions differently, but we did not observe a "vertical only" conception.

Distance from opening. Our preliminary studies involving the *N*-tube of [4] suggested that the "distance from opening" conception (option *G* in 3-shape) is quite prevalent, but only 2-10% of our students chose that option.

Uniform. Shamu option *D* suggests that pressure has the same value everywhere in a fluid. The number of students choosing this option pre-instruction is very small (3-5%). After instruction, this option is negligible in the trig and calc classes, but is more significant, 15% (F11) or 9% (S12), in the conceptual classes. We suspect this result is due to the stressing of incompressibility in the conceptual course, along with a lack of distinction between density and pressure.

SUMMARY

Our college students evince many of the same difficulties with pressures identified by studies involving younger students. In particular, the "amount above" and "enclosed" conceptions were popular choices. We did not see a strong number of students suggesting that pressure is larger at points closer to a wall, or that the pressure is the same everywhere in a fluid. We saw a modest number of students treating horizontal and vertical dimensions differently – far short of the ~50% seen in study [6]. The 3-shape question did not elicit the expected popularity of the "distance along tube" conception. We will continue to refine our diagnostic questions to better distinguish between specific conceptions, and to address each conception multiple times.

ACKNOWLEDGMENTS

Partial support for this work has come from the Swezey Scientific Instrumentation and Research Fund. The authors would also like to thank the other members of the GCC PER group who have contributed to this project: Elizabeth Carbone, Sam Cohen, Kathryn Merrymon, and Jason Wetstone.

REFERENCES

1. M. E. Loverude, P. R. L. Heron, and C. H. Kautz, *Am. J. Phys* **78**, 75 (2010).
2. U. Besson, *Int J Sci Educ* **26,** 1683-1714 (2004).
3. F. F. Camacho and L. G. Cazares, *Sci. Educ*. **82**, 15–29 (1998).
4. E. Engel Clough, and R. Driver, *Research in Science & Technological Education* **3**, 133-144 (1985).
5. M. Mayer, "Common sense knowledge versus scientific knowledge: The case of pressure, weight, and gravity" in *Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics*, edited by J. D. Novak, Cornell University, Ithaca, NY, 1987, pp. 298–310.
6. P. A. Giese, "Misconceptions about water pressure" in *Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics*, edited by J. D. Novak, Cornell University, Ithaca, NY, 1987, pp. 141–148.
7. P. P. Kariotoglou, and D. D. Psillos, *Research In Science & Technological Education* **11**, 95-108 (1993).
8. G. Fassoulopoulos, P. Kariotoglou, and P. Koumaras, ***Res Sci Ed***, **33**, 71-87 (2003).
9. This conception is mentioned in reference [8] and in P. Kariotoglou, D. Psillos, and O. Vallassiades, *Phys. Educ.* **25**, 92-96 (1990); they cite the following, which we have been unable to obtain: D. Koliopoulos, P. Kareiotoglou, and D. Psillos. "La force dans le contexte des liquides: une premiere approche des college en Grece," Feuilles d' Epistemologie Appliquee et de didactique des sciences, pp. 59-65 (1986).
10. The Physics Education Group at the University of Washington, L. C. McDermott, and P. S. Shaffer, *Tutorials in Introductory Physics*, Upper Saddle River: Prentice-Hall, 2002.
11. The "3-shape" question is a modification from one developed by James Vesenka and presented at the Jacksonville AAPT Winter 2011 meeting. Source [5] generated the idea for the "Balloon P" question.