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Overcoming misconceptions and enhancing student's physical understanding of civil and environmental engineering fluid mechanics

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N. B. Kaye and J. Ogle

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N. B. Kaye[a] and J. Ogle

AFFILIATIONS

Glenn Department of Civil Engineering, Clemson University, Clemson, South Carolina 29634, USA

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[a]Author to whom correspondence should be addressed: nbkaye@clemson.edu

ABSTRACT

Undergraduate students of fluid mechanics bring a range of preconceptions to the classroom. The sometimes counterintuitive nature of fluid mechanics means that many of these preconceptions are, in fact, misconceptions. Such misconceptions can be hard to address and can persist even among nominally high-performing students. A pedagogical approach (i.e., predict, test, and reflect) is presented. The approach provides an effective structure for addressing and correcting misconceptions through the use of low-cost hands-on activities that students can quickly and easily undertake during regular class time. The activities all have the same structure of describing the activity, having students make a prediction based on their intuition/prior experience, testing that prediction using simple, low-cost activities, reflecting on the success or failure of the prior prediction, and analysis of the activity to illustrate the correct conception of the flow. Course evaluations indicate that students have found this approach very helpful in improving their conceptual understanding in an introductory engineering fluid mechanics class.

I. INTRODUCTION

Undergraduate civil and environmental engineering students often find fluid mechanics concepts to be counterintuitive. For example, ask a class how the pressure changes when water flows through a horizontal pipe contraction, and significant numbers will incorrectly state that it goes up. There are likely many reasons for this misconception. One direct observation that many students have experienced relates to outdoor watering hoses. If you squeeze the end of a hose, the force you feel if you place your hand in the stream goes up compared to when the hose end is not squeezed. Likewise, if you ask a class if you need to blow harder or softer to blow a large soap bubble, many students intuition is that you need to blow harder, most likely drawing an analogy with blowing up a balloon. Misconceptions such as these can cause a disconnect between the theoretical calculations in the class and a student's physical understanding of a particular flow. It is, therefore, important to give students opportunities to improve their physical understanding of the flows they are learning about and to correct these misconceptions.

This paper provides a pedagogical approach grounded in active learning to change common fluid mechanics misconceptions. Herein, we present three examples of hands-on learning activities that help students reframe misconceptions. These examples have been used extensively and successfully in a junior-level introductory fluid mechanics class in civil engineering. The class is typically taught in sections of 60–80 students and is a required class for students majoring in Civil Engineering, Environmental Engineering, and Bio-Systems Engineering. The three in-class activities have a short duration (5–10 min each) and are relatively low budget with a total cost of around $2.50 (USD) per student. Given that every student conducts their own experiment, these can also be used in fully online courses.

Active engagement in the classroom has shown to increase performance in traditional class tests and in concept inventory (CI) performance across a range of STEM subjects.[1] This result held across a broad range of active learning strategies of varying levels of intensity. One example of active engagement is to flip the classroom. In a flipped classroom, students are required to review the class material beforehand and then spend all the class time actively engaged in various activities such as working on problems in groups or individually. This approach was tested by[2] over a one week (three class) period in an introductory calculus based physics class and demonstrated that students in the flipped classroom performed substantially better on a review test than the control group. Flipping a classroom requires significant amount of preparation as the class material needs to be made available prior to the class period and a series of tasks prepared to actively engage the students during the class period. An even more extreme example of engaging students is described in Ref. 3, which describes the development of an entire general education physics class around the topic of cooking. The course included guest lectures by chefs and cooking labs that were related to an "equation of the week" introduced by the physics instructor. However, there are a broad range of tools for active learning in the classroom that do not require a complete overhaul of a course. The goal of this paper is to present details on a set of short, easy to implement in-class activities that can be used in an introductory engineering fluid mechanics class. The activities are low cost, and each take only a few minutes to implement. Therefore, they can be introduced into a traditional lecture course with minimal additional effort.

The remainder of this paper is structured as follows. In Sec. II, we briefly review the literature on concept inventories and concept change theories. Section III reviews the pedagogical approach (i.e., predict-do-reflect) used in conjunction with in-class activities. Section IV describes, in detail, the implementation of three in-class activities that cover concepts in surface tension, Bernoulli's equation, and linear momentum. Student feedback is briefly reviewed, and conclusions are drawn in Sec. V.

II. BACKGROUND

Chi and Roscoe[4] noted that students come to a class with what they call "naïve knowledge" about the topic. Some of this prior knowledge is correct and some is not. The authors divided incorrect prior knowledge into two categories. First, are preconceptions that can be easily corrected by providing additional information. They provide examples of preconceptions, such as "Insects are not a type of animal," that are largely definitional. Misconceptions, however, may be more robust and harder to address. They found this to be particularly true when related to concepts that are not directly observable—such as force, pressure, and energy. Unfortunately, these misconceptions can persist throughout an entire class even for nominally high-performing students.[5]

There are tools for identifying conceptual misunderstandings. For example, the use of concept inventories (CIs) early in a semester can provide data on areas where students may need additional help. Concept inventories are typically developed using a Delphi process to define fundamentally important concepts that are also prone to misconception.[6] Student misconceptions are carefully identified through open-ended questions and coded as distractor response options within the inventory.[7] There is an excellent collection of concept inventories for a range of STEM subjects maintained by Oregon State University faculty[8] with almost 3500 conceptual questions. An alternative to the concept inventory for identifying student misconceptions is student interviews[5] though this is not recommended when trying to assess common misunderstandings in a large class.

In 2003, Martin *et al.*[9] reported on the development of a specific concept inventory for mechanical engineering fluid mechanics (ME-FMCI) building off prior concept inventory models for force concepts[10] and heat transfer.[11] In the process, they determined that students and instructors often use different languages in describing their understanding. Students also tended to miss subtle differences in component arrangements that faculty deemed important. Thus, the development of a concept inventory without consideration of these findings would be difficult at best for students. The initial list included three principle areas with approximately 25 concepts. The authors iterated the FMCI numerous times and used it for assessing fluid mechanics courses with average gains of 18%–30% on all questions.[12] Watson *et al.*[13] later tested the ME-FMCI for use in civil engineering courses with a learning gain of only 11%. This difference was attributed to the focus on mechanically inclined questions.

One particularly important finding was made by Chi *et al.*[14] who used ontological categories to classify entities including matter, processes, and mental states. They report that many engineering concepts not only belong to the *processes* category but also involve *matter*. Thus, they found that students may easily confuse the matter with the process. This is similar to the water hose example presented above where students perceive the water matter to assume the qualities of the process. Chi and collaborators[4] state that "the process of categorical shift is so difficult, that it can seldom be accomplished through lecture alone." A significant study of interactive engagement[15] with over 6000 participants indicates that conceptual and problem-solving test performance is greatly improved in comparison to traditional practices. Furthermore, active learning techniques (i.e., peer instruction, electronic response, and interactive demonstrations) were found by Welsh[16] as particularly effective in third-year courses for improving conceptual and problem-solving skills. The response systems engage students and create a personal touch in large classes, interactive demonstrations allow students to test their responses, whereas peer instruction can allow students to discuss concepts, reasoning, and dispel misconceptions.

III. PEDAGOGICAL APPROACH

While there are easily accessible tools for identifying misconceptions, correcting misconceptions is more complex. The proposed pedagogical approach is to follow a predict-test-reflect approach through active learning. The basic idea is to have students (a) make a prediction based on their preconception of a particular physical phenomenon, (b) undertake an activity that can test that prediction, and (c) reflect on whether or not the prediction was correct. When students are confronted with the failure of the preconceived understanding, they are more open to an alternate conceptual understanding of the phenomena.

The goal of each activity is to challenge typical misconceptions about a particular aspect of fluid mechanics. Therefore, it is important that, before the activity, students should make a prediction based on their understanding of the activity. The same five-step structure is used in each of the activities described in this paper. The five steps are Describe, Predict, Test, Reflect, and Analyze. They are described in more detail below.

1. Describe the activity—The first step is for the instructor to describe the upcoming activity in detail with particular focus on what the students are about to do. This description needs enough detail, so that the students can easily undertake the activity and be aware of what they are supposed to be observing. The observation should be fairly simple, so that there is no ambiguity with the results.
2. Predict a result—Once the students know what they are about to do, they are asked to make a prediction about the flow. Electronic

response systems are useful for this step. While clickers are used in the classes described, the term is used generically, and other polling tools can be used such as Kahoot! and Mentimeter. We often give the students a multiple-choice list of options from which they can choose their prediction. It is important that the students have a moment to think about the activity and make a prediction based on their understanding of the activity and the fluid mechanics topic. However, the prediction should be low stakes. When clickers are used to log the prediction, the instructor only awards points for participation, not for having the correct intuition about the activity to follow. Thus, the prediction should not impact their grade in any significant way.

3. Test the concept with a hands-on activity—After the student's make their prediction, the students carry out the activity. There should be enough time to do the activity multiple times, so that they are clear on the result. In many cases, the activity requires the students to stand up and move a bit, which has the added benefit of reengaging any students who have become distracted throughout the class time.
4. REFLECT on the prediction—After the activity is completed, the students should discuss their observations with the students around them and reflect on their predictions. If clickers have been used to log student predictions, then it is also worth revisiting the prediction clicker question to see if students have changed their mind about the problem. The point of the reflection is to confront students with their failed predictions. That is, they should reflect on what they may have misunderstood about the problem or what assumptions they made that may be incorrect. As noted in the introduction, the recognition of a failed prediction opens the door for students to change their view of the topic.
5. Analyze the problem—Once the students have reflected on their preconceptions, it is important to explain their observations. The key is to demonstrate how the (often counterintuitive) result is explained using tools the students have at their disposal. One of the benefits of the analysis step is that it makes a direct connection between a theoretical analysis and a physical observation. This is particularly valuable if the observation is counterintuitive.

The examples presented below are very simple and easy to organize. The total equipment cost for all three is less than $2.50 per student (when purchased in bulk). However, this simplicity helps make them memorable. They can also be used as memory aids in reviewing class material later in the semester.

IV. EXAMPLE DEMONSTRATIONS

Below are descriptions of three low-cost activities that introduce students to surface tension by blowing bubbles, Bernoulli's equation by trying to blow a ping-pong ball out of a funnel, and the integral form of the momentum equation by observing movement in a bendy straw with differing airflow directions. In each example, we describe the context, procedure, and outcomes of the activity. With the exception of the first activity, the activities described below have been adapted from activities developed by others. The authors are unaware of the origins of the second activity, but note that the third activity was first introduced to the authors through a conference paper by Professor Mironer.[17]

The activities described below are part of over 70 activities and demonstrations published online[18] by the first author. The choice of activities presented was based on three criteria. The first criterion was cost. The activities presented each cost less than $2 USD per student. This means that each student in the class can participate in the activity. Second, the activities span a range of fundamental fluid mechanics topics (i.e., fluids properties, Bernoulli's equation, and linear momentum). Third, the format of each activity is slightly different. For example, the Bernoulli activity requires students to make a single prediction prior to the activity, whereas in the momentum activity, the students make an observation and are then asked to make a prediction about a similar flow based on their initial observation.

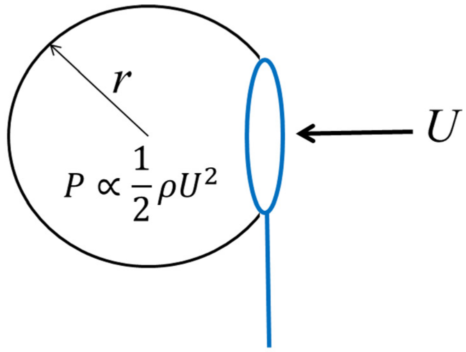
A. Blowing soap bubbles

The focus concept for surface tension in this class is the capillary effect. The main application in the class is in adjusting for surface tension effects in manometers, which students will use in an accompanying laboratory class. While surface tension has many applications in civil and environmental engineering, particularly in sub-surface flows, these topics are left to other classes. The focus is, therefore, on the pressure change across a curved fluid–gas surface. The activity described in this section is designed to qualitatively demonstrate that the pressure change is inversely proportional to the radius of curvature of the surface. The demonstration is used in the first two weeks of the class before we start on hydrostatics and dynamics. The only equipment required is a bottle of soap bubble mixture. They can be purchased in bulk for less than $0.50 (USD) per bottle. Each bottle can last multiple semesters. An image to the equipment and a schematic of the experiment are shown in Fig. 1.

The five-step process of this demonstration is as follows.

1. Describe: The students are all given a bottle of soap bubbles to conduct an activity. The activity is described by the instructor as having two parts. The first step is to have students gently blow on their hand and then blow harder on their hand. This is done before describing the bubble activity. The instructor then explains that the force they feel on their hand is related to the stagnation pressure from them blowing, and that the harder they blow, the higher the stagnation pressure. This explanation is kept at a very low qualitative level as the class has not covered Bernoulli's equation at this point in the class. The instructor then explains that when blowing bubbles, the pressure on the inside of the bubble is proportional to the stagnation pressure from their breath. Again, this is an overly simplified explanation of blowing bubbles. The goal is simply to give the students a basic idea about the relationship between how hard they breathe and the pressure inside the bubble. Only at this point is the full activity described.
2. Predict: The students are asked to answer the question "how do I blow the biggest bubble?" If the instructor is using clickers, they can poll the class to find their intuitive response to this question. The options given are (a) "by blowing harder" and (b) "by blowing less hard."
3. Test: The students are then instructed to test out their hypothesis by trying different approaches to blowing bubbles. The students are given a couple of minutes to blow bubbles before being reengaged by the instructor.

(a)



(b)

FIG. 1. (a) Photograph of the equipment needed for the activity. (b) Diagram of blowing a bubble with an air speed of U forming a bubble or radius r with an internal pressure proportional to the stagnation pressure.

4. Reflect: The students are then asked the same question, and the answer is almost universally (b), that bigger bubbles are formed by blowing more gently.
5. Analyze: The analysis portion of this particular activity is not an explanation of the phenomenon but rather a statement of the equation for the pressure change across a curved surface. The instructor notes that if students blow more gently (lower stagnation pressure) to form bigger bubbles, then the pressure change across the surface is related to the inverse of the radius of curvature of the surface. The instructor then writes the basic equation on the board, namely,

$$\Delta P = \sigma\left(\frac{1}{r_1} + \frac{1}{r_2}\right). \quad (1)$$

The activity is a good lead-in to the equation and gives them a physical experience that agrees with the equation presented. The demonstration aids memory in two ways: (1) the students recall that the pressure change is inversely proportional to the radius, and (2) it is a simple way to remember that the pressure is higher on the inside of the curve. When reviewing the topic prior to tests, the instructor can recall their experience in blowing bubbles to recall and emphasize both these points.

B. Blowing a ping-pong ball out of a funnel

The second activity illustrates some of the counterintuitive flows that are described/explained by Bernoulli's equation. This activity is used either in the class where Bernoulli's equation is derived or in the following class. The students have already covered control volumes and conservation of volume. Note that civil and environmental engineering students' fluids almost always deal with incompressible flows with constant density, so conservation of volume is used instead of conservation of mass.

The five-step process of this demonstration is as follows.

1. Describe: The students are each provided with a funnel and a ping-pong ball. If purchased in bulk, the total cost is less than \$1.50 (USD). The equipment needed is shown in Fig. 2(a). Note that it is important to find a funnel that is smooth inside, so that the ping-pong ball can completely block the neck. The instructor then demonstrates what they will be asked to do. The students will be asked to stand up and hold the funnel, so that the funnel neck is pointing vertically upward and the larger mouth facing the floor (vertical orientation is important). The students will then use a finger to push the ping-pong ball up into the funnel blocking the neck. Once the neck of the funnel is blocked by the ball, the students are instructed to blow through the funnel, releasing their finger from the ball at the exact same time as they start to blow. The instructions are given without the instructor actually doing the activity.
2. Predict: The students are then asked to make a prediction about how the ball will be blown out of the funnel. When using clickers, the students are given a statement "The ball will come out of the funnel more rapidly if I blow harder" and asked if they believe it is true or false. Typically, there are significant numbers of students that select "true." If clickers are not being used, then students are just asked to make a prediction without it being logged.
3. Test: Only once, the predictions have been made are the students given time to do the activity. Again, the students need to stand up to complete the activity. This gives them an opportunity for a brief mental break and to reengage with the class if they have become distracted.
4. Reflect: Once the students have completed the activity, they are asked the same true or false question. Almost universally, the response is that the statement is false. The instructor then asks the class for any other observations that they made during the activity. Responses typically include phrases like "the ball gets stuck" and "It rattles around a bit." Both these observations will be explained in the final analysis step.
5. Analyze: The analysis brings together conservation of volume, Bernoulli's equation, and some standard assumptions about outlet conditions. The control volume diagram and accompanying streamline are shown in Fig. 2(b). The essence of the analysis is as follows. First, we note that as the ball starts to fall out of the funnel, there is a small gap between the ball and the funnel on the top half of the ball [point 1 in Fig. 2(b)]. Conservation of volume requires that the velocity of the air in this gap is much higher than the velocity out of the funnel. Furthermore, the pressure at the outlet [point 2 in Fig. 2(b)] is approximately atmospheric (zero gauge pressure). Therefore, there is a negative pressure induced above the ball, which pulls it back toward the funnel. However, as soon as the ball blocks the flow when the ball is pushed back up toward the neck, the induced low pressure

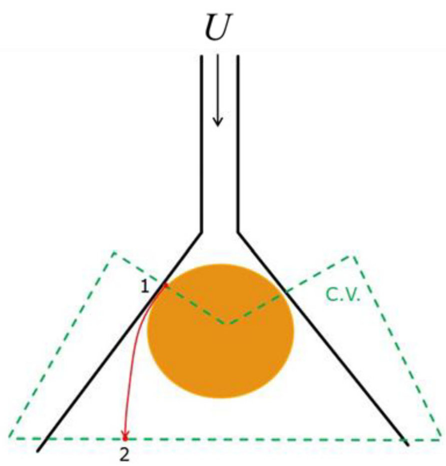


FIG. 2. (a) Image of the equipment required for the second activity. (b) Diagram of the funnel ping-pong ball Bernoulli activity showing the control volume and streamline drawn from the contact point to the funnel outlet.

is replaced by the stagnation pressure from the person blowing through the funnel. This pushes the ball back down. This cycle of pushing the ball out only for the induced low pressure to draw it back upward repeats for as long as the student can keep blowing through the funnel. This cycle also produces the rattling noise that the students observe. For this to work, the ball has to have very low inertia, so that it can change direction rapidly. This is true for ping-pong balls that have a mass of a few grams[19] such that their inertia is negligible.

C. Blowing through bendy straws

The final demonstration has students blow through bendy straws. Again, the cost is minimal. A pack of 500 can be purchased for less than $10 (USD). This is based on an activity that the authors first saw described by Professor Mironer.[17]

The five-step process of this demonstration is as follows.

1. Describe: In this activity, the students do the first part of the experiment and are then asked to make a prediction about the second part. In the first part, they are given a bendy straw and told to bend it to form a 90° angle. They are then instructed to hold it loosely in their lips with the long part of the straw pointing down (this keeps the impact of gravity out of the analysis) and then blow through the straw. Unsurprisingly, the straw deflects away from the direction of the outflow.
   The instructor then goes over the analysis on the board. The integral form of the linear momentum equation is applied in the horizontal (x) direction (eliminating the inflow and gravity from the analysis)
   $$F_x = \rho Q U_{out.x} - \rho Q U_{in.x} = \rho U^2 A - 0.$$
   The analysis requires that the straw applies a force (F_x) to the flow to generate the horizontal momentum at the outflow. Therefore, there is a reaction force that the flow applies to the straw causing it to deflect in the direction opposite to the outflow. See Fig. 3(a) for the control volume used in the analysis.
2. Predict: Once the analysis of the first test is complete, the students are asked to make a prediction about what will happen if, instead of blowing air out through the straw, they suck air-in through the straw. When this is done with clickers, the students are given a set of three options:
   (a) The straw will deflect to the right
   (b) The straw will not deflect by a significant amount
   (c) The straw will again deflect to the left.
   If clickers are not used them, the instructor discusses the three options with the class and asks them to choose the predicted outcome. There is usually a divide in the responses at this point. Some students see the problem as reversible, such that the deflection will be equal in magnitude but opposite in direction to the first case. Some students select (c) recognizing that the flow changes the direction, and also that what was the outflow is now the inflow, so the unknown force the straw applies to the flow would be the same.
3. Test: Once the prediction has been made, the students are asked to test their prediction. This process can be a little controversial, as it is hard for students to judge if the magnitude of the deflection is equal to the first case (option a) or is less than the first case (option b). This is particularly true if they are invested in their prediction.
4. Reflect: The instructor then demonstrates the two flows, illustrating that the straw does not deflect much when air is sucked through the straw. The students are then asked to compare their observations with their prior prediction.
5. Analyze: The difference is in the pressure condition at the end of the straw. When blowing through the straw, the flow separates at the exit, and the pressure is approximately atmospheric at that point. However, when sucking through the straw, the flow is drawn into the straw by an induced low pressure (negative gauge pressure) at the end of the straw. This can be shown by drawing

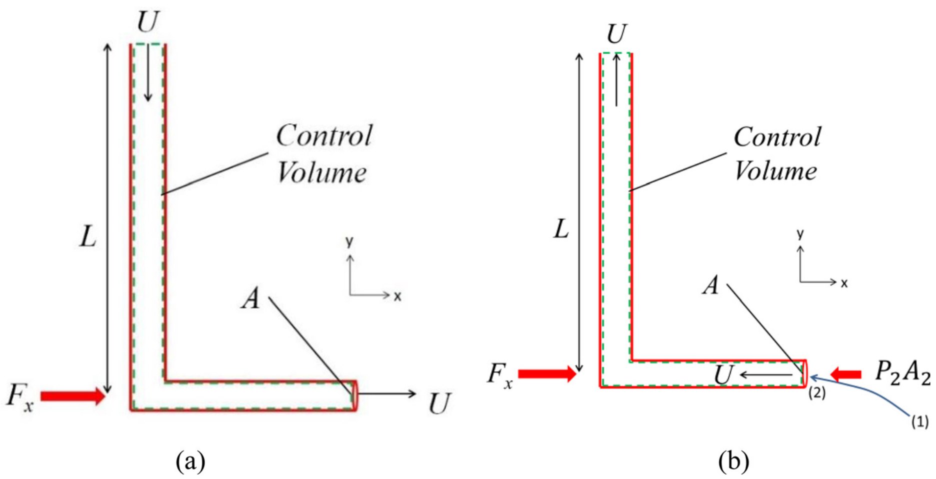


FIG. 3. Diagrams of the two cases for the bendy straw momentum activity. The diagrams show the analysis control volume, the horizontal forces acting on the straw, and the flow direction. (a) Blowing air through the straw and (b) sucking air through the straw showing a streamline from the ambient to the straw inlet and the force due to the induced negative pressure at the end of the straw (point 2). By convention, the unknown force F_x is shown in the positive x direction.

a streamline from the stationary ambient to the end of the straw [shown in Fig. 3(b)] and then applying Bernoulli's equation. The pressure at the end of the straw can then be shown to be $-\frac{1}{2}\rho U^2$. However, as pointed out by Mironer,[17] there is an additional pressure drop due to the "boundary layer separation and the formation of an eddying flow at the lip of the tube," which is approximately the same magnitude as the pressure drop due to the acceleration of the ambient air into the tube, i.e., $\Delta P \approx -\frac{1}{2}\rho U^2$ such that the pressure at the inlet is $P_2 \approx -\rho U^2$. This adds that a negative pressure adds an additional force to the analysis, so that the momentum equation in the x direction becomes

$$F_x - P_2 A = \rho Q U_{out.x} - \rho Q U_{in.x} = 0 - \rho U^2 A$$

or

$$F_x - \rho U^2 A \approx -\rho U^2 A.$$

Therefore, the force that the straw has to apply to the flow is approximately zero and the straw does not deflect.

It should be noted that this can be a difficult activity to undertake as the student has to hold the straw vertical in their lips and blow or suck through the straw without having their lips move causing the straw to deflect. Hence, the instructor repeats the activity after the students have undertaken it. In the original demonstration described by Mironer,[17] the straw is held in a clamp to avoid the lips problem. However, this requires more equipment, particularly if one goal is to have all the students do the activity.

V. RESULTS AND CONCLUSIONS

Students arrive in fluid mechanics class with a range of preconceptions and misconceptions. Addressing the misconceptions can be a major challenge to instructors. Misconceptions can persist even among high-performing students who succeed in the class. One of the most effective ways to correct misconceptions is to confront students with failed predictions that follow from their misconception. Herein, we have presented a sample of three quick and inexpensive in-class activities that can be used as part of this process. Each activity can be done in a few minutes during class at negligible cost (the only non-reusable component is a 2 cent bendy straw). The key is to ensure that students make a prediction about the outcome of the activity prior to undertaking it. Any failure in their prediction creates an opening to correct their misconception.

Feedback on student's perception of the value of these activities has been very positive. Feedback has been collected through clicker questions in class and end of semester online course evaluations. In one clicker survey, the students were asked to state if they thought that the class should include fewer of these activities and demonstrations, the same, or more. 97% responded that they would want the same number or more of these types of activities. Over a three semester period, the students were asked if they agreed with the statement "Do the in-class demonstrations help with the class material and were they a positive part of the class?" Again, 97% of responses over the three semesters were in agreement with the statement. These results are consistent with student comments made in end of semester online course evaluations.

Over the past 14 semesters in which the class was taught in person, i.e., prior to the pandemic, the in-class activities used in this course have been mentioned by students in the comments section approximately 250 times. This means that 25% of students who responded to the course evaluations explicitly mentioned the in-class activities used. The comments were almost universally positive. Selected comments that are typical of student responses included the following phrases "… neat ways to apply the material ourselves," "They help make concepts come full circle by giving you a look at what is actually happening," "made learning the material more enjoyable and were actually very relevant and applicable to the material we were learning," "… easily the most helpful and effective way to learn this course material," "It helped me understand the concepts," and "… helped concepts make more sense."

The activities described above were introduced in response to anecdotal evidence of students struggling with particular concepts and in response to student surveys indicating the topics with which they had the most difficulty. Student surveys were particularly clear on the need for an activity related to momentum (the bent straw activity). They were not added as part of a detailed educational study, and there is clearly scope for a more detailed analysis of the benefits of this approach using rigorous assessment instruments such as concept inventories. However, the response from students in their end of semester evaluations of their instructor has been very positive, and there is clearly a gain in the students own perception of their understanding as shown by these comments. It is also worth noting that students perception of learning can lag behind their actual learning when active learning approaches are implemented[20] possibly due to the additional mental effort required of students during active learning, though this study focused on more intense implementations of active learning over a short period during an existing class that otherwise consisted of lectures and demonstrations with the only active learning being occasional quizzes or concept questions.

The move to remote learning brought on by the COVID-19 pandemic has limited the use of these activities. The initial move online was on short notice, and there was no opportunity to distribute equipment to individual students. In the second COVID-19 semester, the class was taught asynchronously online. In the most recent semester, this class was taught face-to-face but with a classroom mask requirement. This required the activities to be done outside at the very end of class when students had already packed their notes away. As such, it was not possible to formally log the students predictions and observations. This likely explains why they were only mentioned in only 2 of 54 responses that semester.

It is possible for the instructor to use these activities as classroom demonstrations while still having the students make their predictions. That is, the instructor can perform the activity for the class rather than having the students do the activity themselves. This would save the time taken to hand out the equipment and is obviously more sanitary given the current pandemic. However, the time saving is minimal as the equipment can be passed out while the instructor is explaining the activity. Having only the instructor do the activity means that the students do not get the same mental break that standing up and blowing bubbles (or funnels or straws) provides. While there is still some dispute over the idea that students have a 15 min attention span,[21] it is certainly the case that some students will be distracted at various points in a class period, and that standing up and doing so sort of activity relevant to the class material will give them an opportunity to re-connect.

The hands-on activities described herein are a sample of over 70 activities and demonstrations published on a blog maintained by the first author.[18] There are other sources of ideas for such activities including a book published by the American Society of Civil Engineers[22] and one by Granger.[23] UC Berkeley also developed a broad range of fluid dynamics demonstrations that are archived on various websites (e.g., https://www.nhn.ou.edu/demo/fluid/fluid.html). However, these demonstrations often require specialized equipment, and the descriptions provided in the archives are very limited. Readers are also directed to Ref. 24 for a range of fluid mechanics demonstrations and Ref. 25 for a very extensive range of multimedia fluid mechanics resources. There are also numerous YouTube channels that can help improve students conceptual and physical understanding of the subject. Examples include Prof. John Cimbala's Two-Minute Fluid Mechanics playlist and a range of science communication channels that include fluid mechanics topics such as fyfluiddynamics, Veritasium, and SmarterEveryDay. Though any YouTube videos should be carefully vetted prior to use, the authors have found some of the explanations to be superficial, imprecise, or, occasionally, incorrect.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

DATA AVAILABILITY

The data that support the findings of this study are available within the article.

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