Using Cartoons to Enhance Engineering Course Concepts

Dr. Edward James Diehl P.E., University of Hartford

Dr. Diehl received his PhD in Mechanical Engineering from the University of Connecticut in 2016, his MS in Mechanical Engineering from Rensselaer at Hartford in 1996, and BS in Marine Engineering Systems at the United States Merchant Marine Academy. He worked as a Professional Engineer in the maritime industry for 17 years and taught mechanical engineering courses for the past 8 years. His research interests include simulation of mechanical vibration in gear systems for condition monitoring and engineering pedagogy.

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Abstract:

Cartoons, while often associated with a younger audience, can assist some college engineering students in making relatable connections to course concepts and breaking down barriers to understanding. Intermediate engineering courses such as Dynamics and Fluid Mechanics, typically taken sophomore and junior year, contain numerous essential ideas that students must completely understand and build upon as the courses progress and retain for follow-on classes senior year. Cartoons, if sufficiently relevant and memorable, can help a portion of the engineering student population "grasp and retain" concepts. This paper describes experience creating and using original cartoon characters in teaching Dynamics and Fluid Mechanics. Development of the characters, adapting them for each concept throughout the semesters, and examples where they are incorporated in the class notes, learning management system, classroom slides and classroom whiteboard work are described. Some student feedback is presented, and future research to quantify effectiveness is proposed. Lessons learned and advice for other instructors wishing to incorporate cartoons into their lessons is also provided.

Introduction

Two years ago, a colleague described an ASEE article she'd read about using science comics to teach chemistry [1] and suggested the author try doing something similar. Scheduled to teach Fluid Mechanics in the Fall and Dynamics in the Spring, cartoon characters were created for both classes: Wetted and Vapes" for Fluids (Figure 1), "Newtdog and Wormy" for Dynamics (Figure 2). Instead of comics, these characters were drawn involved in various topically relevant situations without captions. Throughout the next two semesters over 60 cartoons were created and incorporated into the courses in a variety of ways. These included embedding the images in handout notes, featuring them in the Learning Management System (LMS) front page to introduce topics, drawing them on the board before class, and discussing and critiquing them with students. This became an interesting way to have fun with topics that aren't necessarily enjoyable, and students responded with interest and positive feedback. The challenge of imagining a single image that conveys the central idea of each topic or expresses distinctions within concepts provided an opportunity for instructor creativity. With each new cartoon and new challenge, the author grew more enthusiastic about the potential benefits of using cartoons in these engineering courses.

The purpose of this paper is to share the author's experience using cartoons in engineering classes. Also presented here is the approach to developing the characters, examples of inspiration for cartoons that capture topics, and the technique for turning pencil sketches into color cartoon images via free and common software. It is hoped that this information will inspire and assist other engineering instructors to create cartoons for their engineering classes.

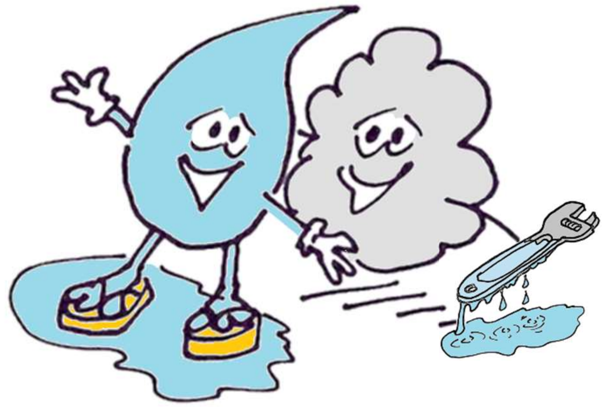


Figure 1. The Fluid Mechanics: Wetted and Vapes.

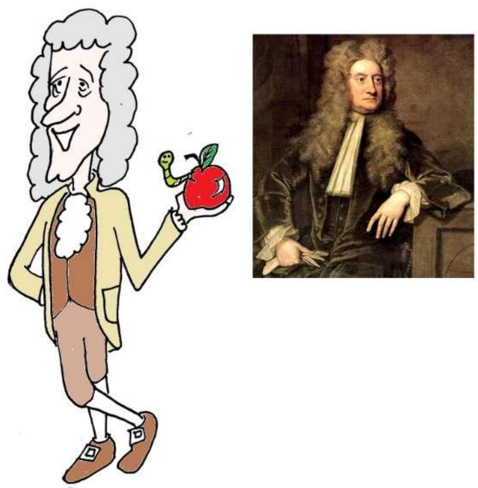


Figure 2: Newtdog and Wormy (inset painting by Sir Godfrey Kneller [2])

Objectives

There were three primary objectives with these cartoons: concept mnemonics, classroom humor and discussion provocation.

The “concept mnemonic” aspect attempts to capture a concept by making the image memorable and providing a graphical association. This mnemonic can be reinforced by referring to the cartoon to provide a “hint” when entire class is asked a Socratic question and waiting for them to respond. Typically, when one of these questions is asked, the ensuing blank stares and silence become a waiting game between teacher and class, often eventually ending in surrender with the teacher answering the question. If one were to recall their own experiences as a student when asked these questions, they most likely will remember the difficulty or even some mental paralysis. Referencing a mnemonic cartoon can nudge students towards the answer and make the lightbulb go off and an answer come out. Breaking that Socratic question paralysis is amongst the goals, but some longer-term mnemonic value is possible beyond the present semester. The retention of some core concepts from semester to semester and then even after graduation via these simple cartoons is an even more ambitious goal.

Many students come into Dynamics and Fluid Mechanics forewarned by their peers about the difficulty of the courses and the drudgery they're about to endure. Another objective in introducing cartoons was to lighten the classroom mood. Described later when discussing the character creation, Sir Isaac Newton is purposefully drawn to appear friendly and a little goofy to make him more relatable than the stuffy portrait with a powered wig seen in Figure 2. Wetted and Vapes are characters who act as somewhat mischievous and silly mascots for the class. A potential hazard here is to come off as childish and thereby turn off some students who might feel the cartoons were beneath them.

In addition to the mnemonic nudge for breaking a Socratic question stalemate, students are encouraged to question the cartoons, even critique them or suggest alternative ways to represent the concepts. It is hoped that by discussing the creation of the cartoons and getting their feedback that they would also pick apart the concepts represented in more detail.

Literature Review

A literature review of existing pedagogy on STEM cartoons and comics was preformed after the two semesters of cartoons was finished, rather than before. There are many "science comics" and a fair amount of pedagogy research about them. While it would have been greatly beneficial to perform this research before spending so much time and effort, the approach taken was somewhat autodidactic, allowing for a fresh perspective.   The objectives in creating these cartoons described in this paper were somewhat different from most of the examples and papers found in the literature search. The typical approach discussed in the literature are comic books, comic strips and captioned cartoon images, while the cartoons presented in this paper are individual drawings without words that attempt to have the image alone make each individual concept memorable.

The most basic of cartoons and comics have been used to provide instructions. Wirth and Burtt [3] wrote a short 1945 paper "Teaching Technique through Cartoons" which reminds the author of old Department of Defense safety manuals, showing right and wrong ways to perform tasks. Hirst [4] describes cartoons as visual mnemonics that make instructions easier to remember and notes that ancient Romans described how images make subject matter more memorable, especially if the images are "bizarre, striking, [and] unusual."   His example cartoons are also of the instruction manual type.

More pedagogically focused research was performed by Keogh and Naylor [5] regarding "Concept Cartoons" in science. This work has been cited often (for example [6] and [7]) and measurable results confirmed by other researchers [8]. The concept cartoons they created and studied often dealt with science misconceptions and their purpose was to generate classroom discussion of competing ideas amongst the students. This research was focused on primary and secondary education rather than college, but the idea of using the cartoons to generate discussion is relevant. For instance, an often-cited cartoon of theirs involves three children deciding whether putting a coat on a snowman will affect how quickly it melts. While this is a thought provoking cartoon and an excellent discussion starter, the lasting impact is unclear. One might ask, if students will remember or retain the correct conclusion if they were to see the same cartoon after some time has elapsed.

Bahrani and Soltani [9] discuss the pedagogical values of cartoons, describing among the rationale for using cartoons their appeal to visual learners, especially when used at the introduction of a topic. While their focus was on language learners rather than STEM, their points that cartoons have an immediate impact visually that is universal and can help “create a light, playful mood” in the classroom coincide with one of objectives described herein.

More literature was found discussing STEM comics than cartoons [1], [6], [7],[10], [11]. The distinction is important as comics are most often considered “sequential art” [12], while cartoons are single frame images. Comics generally offer a longer narrative than cartoons and much of the pedagogy concerning comics focuses on their appeal as alternatives to other more formal instruction. An excellent example of a mixture of comics and cartoons used for science and engineering instruction is Gonick’s *The Cartoon Guide to Physics* [13] which features plenty of words while remaining more cartoon oriented since it is not sequential. Excellent collections of web-based science comics and animations are [14] and [15] which demonstrate the quantity and quality of independent work being actively generated as well as the enthusiasm for this genre.

Simpler cartoons with the express purpose of memorably capturing a single concept are not as common as science comics, but they do exist. A remarkable example is the Dynamics textbook used at the author’s new university [16] which includes original cartoons throughout in somewhat similar situations as those created with Newtdog and Wormy.

Methodology

For methodology, the approach to creating these characters is described including the inspiration for a few example cartoon scenarios as well as how they were made to look like authentic cartoons rather than just doodles.

Character Creation

The characters used for these cartoons needed to be easy-to-draw and able to perform actions which represent the topical concepts. The simplicity of the drawings allows them to be sketched quickly, so when inspiration occurs, it can be captured without much concern about the details looking perfect. In this respect, the Fluid Mechanics were much better characters than Newtdog and Wormy, requiring much less attention to the physiology or proportions. Finding a cartoon character to represent a topic is perhaps the most important hurdle. An example of this hurdle is the author’s recent inability to decide upon characters for his other courses such as Machine Design. Preliminary ideas for that course are discussed in a later section.

Wetted and Vapes represent the two basic types of fluids: liquids and gases. Choosing a water droplet and a cloud seems natural. Wetted is a water drop who wears flip-flops and always has a puddle under him. Even though he is nose-less and pants-less, his overall features and especially gloved hands were somewhat inspired by a combination of SpongeBob SquarePants and Patrick Star. Some of the appeal to this suggested influence is that many in this generation of students grew up watching SpongeBob SquarePants and the look of the Wetted might feel familiar to them. Wetted is the protagonist in most of the fluids cartoons and has Vapes as his loyal, if not somewhat reticent, companion. Vapes is a cloud with stick arms because how could a vapor ever hold anything anyway. He has a shadow underneath which gives him a bit of a pessimistic look. The name "Wetted" is taken from the "wetted surface area" used in drag resistance of a ship's hull in Naval Architecture. The inspiration for naming the cloud "Vapes" was a student vaping near campus, exhaling huge plumes of smoke in a somewhat ridiculous manner.

"Newtdog" is a nickname a much younger and cooler colleague uses for Sir Isaac Newton to amuse his students. This professor's teaching style is very engaged with the students and quite effective at making Dynamics seem less stuffy and formal. Likewise, his giving Sir Isaac Newton a silly nickname seems to help break down barriers between 20-year-old students and a 330-year-old science. Newtdog is drawn to seem friendly, adventurous (just as Sir Isaac Newton was revolutionary) and a little bit of a dandy with his powered wig, frilly cuffs, long coat and buckled shoes. Also included is a "buddy" for him in Wormy, whose name references an early SpongeBob SquarePants episode. Wormy always appears in the iconic apple that apocryphally led Newton to "discover gravity." Just as Wetted has Vapes for a "straight man" foil character, Wormy is that for Newtdog. Some of the humor comes from Wormy being along for the ride and not always as enthusiastic as the more adventurous Newtdog.

The humor of the characters is important because a primary goal is to add some levity to the course topics and make the images (and therefore concepts they represented) more memorable because of the cartoon absurdity.

Concept Scenario Inspiration

Each cartoon was created by reviewing "the next class," looking for one concept that is central to that class, and then imagining what the characters could do that would memorably represent that concept. Often the important concept is to isolate an important distinction student should make within the topic. Some examples are described below of the thought process that went into creating the image to suit the concept. It should be mentioned that not every effort was entirely successful. Also noteworthy is that some images purposefully have little or no pedogeological benefit but instead were just meant to be funny and contribute to instructor and student report.

The identification of what distinguishes a fluid from a solid is a concept described on the first day of Fluid Mechanics: fluids cannot sustain a shear force. The idea that even the most viscous fluid will continuously deform to an applied shear force is important for the concept of viscosity. In Figure 3 Wetted is shown being cut by a pair of scissors, which students are reminded are often called "shears" by their grandmothers. The inspiration for a cartoon is often the same as the answer to "what is the most important take-away an instructor wants the student to retain?" Anticipating potential usefulness later in the semester for an image and concept is an important consideration and therefore source of inspiration. For instance, later in the course a Socratic question will be asked where the desired answer is "fluids can't sustain a shear". The instructor can allude back to this cartoon if the class needs a hint; perhaps making scissor motions with fingers or reminding the class about the cartoon.

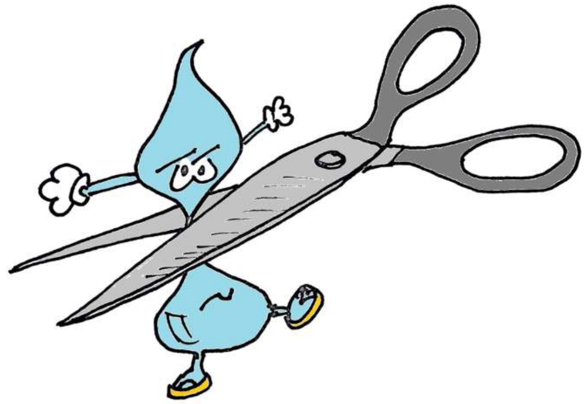


Figure 3: Fluids cannot sustain a shear force.

Making distinctions between concepts became a very common usage for the cartoons. Figure 4 shows The Fluid Mechanics trapped inside C-clamps to represent the incompressible and compressible behavior of liquids versus gases. Part of the motivation/inspiration is to use this image later in the semester when asking leading questions to solicit “liquids are incompressible, and gases are compressible”. One downside of this cartoon is that some students may not be familiar with C-clamps and therefore the visual might carry less meaning for them, even if it is explained what a C-clamp is or does.

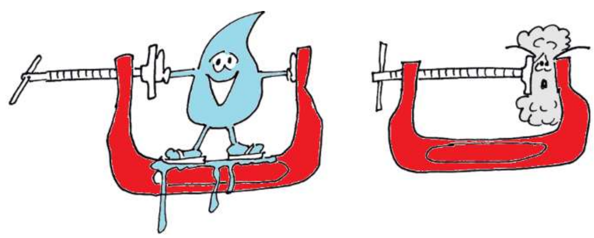


Figure 4: Incompressible and compressible fluids.

A similar but more complicated use of the distinction purpose is included in Figure 5, where Newtdog is representing two different two-dimensional coordinate systems: Polar (aka “Radial and Transverse”) and Path (aka “Normal and Tangential”) coordinates. These two images also had multiple aspects intended for use in the description and discussion of the velocity and acceleration components within these coordinate systems. The essential element of the polar diagram is the reel of the fishing pole to represent $\dot{r}$ and $\ddot{r}$ distinguishing these terms from the complete radial $\left(\ddot{r} - r\dot{\theta}^2\right)$ and transverse $\left(\ddot{\theta} - 2\dot{r}\dot{\theta}\right)$ components of acceleration. The spinning stool helps to establish and isolate $\dot{\theta}$ and $\ddot{\theta}$ as separate variables that also contribute to the complete acceleration components in the polar coordinate system. The key to the usefulness of this image is it can help students to remember what each variable represents in the longer, somewhat confusing equation. Likewise, the path coordinate drawing is useful in several ways including contrasting with polar coordinates. One important take-away in this drawing is that velocity is always tangent to the path and that a normal component of acceleration in needed to keep from flying off the path. Alluding to these images later in the semester was also a prime source of inspiration.

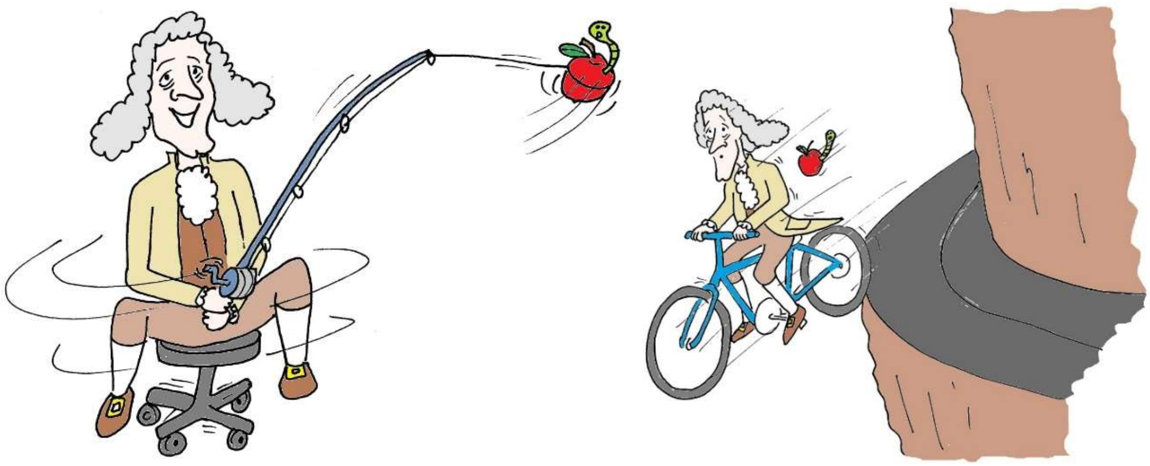
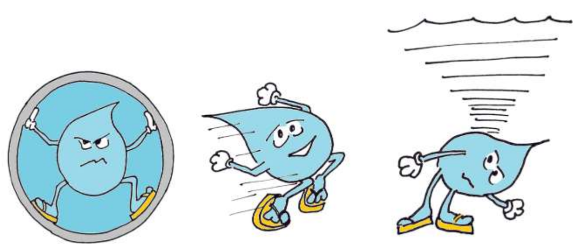


Figure 5: Polar and Path coordinate systems.

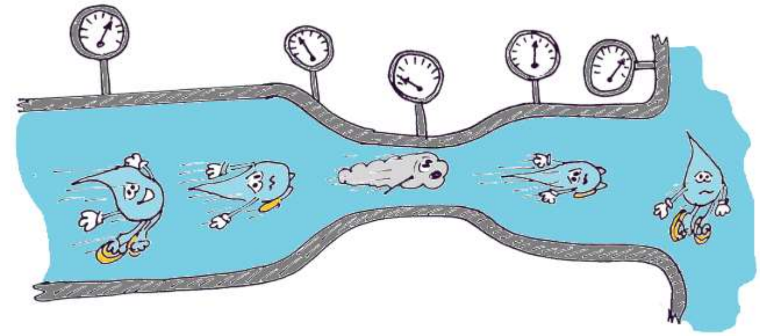
The next three figures represent a successive increase in complexity of related topics. Bernoulli's equation and the Navier-Stokes equations have several various parts, so cartoons representing them need several images. Since the parts can be described as pressures and/or forces present in the equations, each image represents a pressure or force. Bear in mind that these images are embedded in the notes provided for the students to optionally print out before class, so they can write their own notes next to the images and equations. In Figure 6 are three different "kinds of pressure": static, dynamic and hydrostatic that are included in the Bernoulli equation (also shown in the figure). By making three separate images the students can make associations between these three pictures and the three parts within the equation.



$$\underbrace{p}_{static} + \underbrace{\frac{1}{2}\rho V^2}_{dynamic} + \underbrace{\gamma \cdot z}_{hydrostati} = \text{constant along a streamline}$$

Figure 6: Three kinds of pressure represented in the Bernoulli equation.

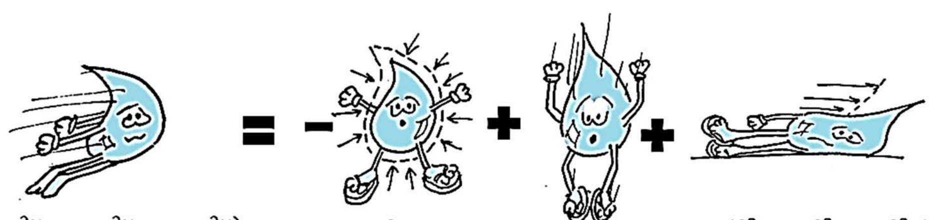
One of the most common calculations using the Bernoulli equation is within a Venturi tube where there is a tradeoff between dynamic pressure and static pressure. While the gages and Wetted's demonstrated speed change indicate this trade-off, the low vacuum at the neck where the highest velocity exists also causes Wetted to flash into Vapes representing cavitation. There are multiple concepts captured here, and the absurdity of the character swap can make the cavitation aspect more memorable.



$$p_1 + \frac{1}{2}\rho {V_1}^2 = p_2 + \frac{1}{2}\rho {V_2}^2$$

Figure 7: Bernoulli venturi tube.

One of the most complicated topics included in undergraduate Fluid Mechanics is the introduction of the Navier-Stokes equation. Due to time and course content constraints, this topic is most often just introductory, and sometimes might not even have a homework assignment associated with it. Since the Navier-Stokes equation contains partial differential equations and can be written in multiple ways (here it is shown only in one dimension), it can be quite intimidating. The motivation for the cartoon was to make each component memorable and broken into parts: dynamic forces equal pressure gradients plus gravitational forces plus shear forces. This was an ambitious topic to tackle for both students and teacher (as well as cartoonist). It may not have been completely successful, but the earlier two cartoons helped to set the stage for this more complex representation.



$$\rho\left(\frac{\partial u}{\partial t} + u\,\frac{\partial u}{\partial x} + v\,\frac{\partial u}{\partial y} + w\,\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \rho\, g_x + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

Figure 8: Navier-Stokes equation.

Many students will recall the apocryphal story of Sir Isaac Newton "discovering" gravity when sitting beneath an apple tree and being struck on the head by a falling apple. This scene is shown in Figure 9 and used to represent the conversion of potential energy into kinetic energy. Adults who grew up in the 1970's will remember the *Schoolhouse Rock* cartoon segment "A Victim of Gravity" which contains the verse "Isaac Newton underneath the apple tree, One hit him on the head, He said, 'That must be gravity!'" [17] A YouTube video of this segment can be played in class, allowing the students to get a chuckle at the 70's kitsch and perhaps at the instructor's expense for being nostalgic. In this instance the idea for the drawing topic came before the concept context where it would be useful.

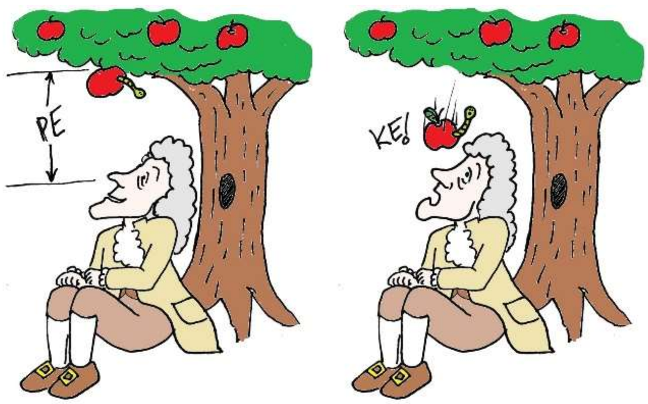


Figure 9: Potential energy versus kinetic energy.

Another source of inspiration are analogies instructors have been using for years. For instance, when discussing Eulerian versus Lagrangian perspectives in Fluid Mechanics, it is common to describe standing on an overpass watching the cars (particles) go by for Eulerian as opposed to riding along in the car (as the particle) to observe the flow. This is shown in Figure 11 using a Ford Mustang convertible which is the author's favorite car, as he's told his students often.

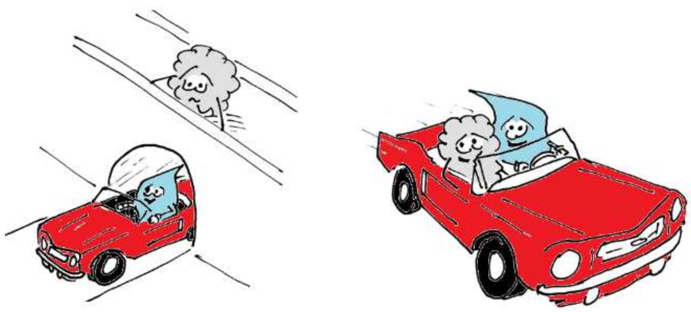


Figure 11: Eulerian versus Lagrangian perspective.

The above examples are intended to explain the inspiration process, but describing how to be creative is rather difficult, so providing examples is perhaps the best way to answer, "how did you think of that?". The ideas mostly occurred to the author while getting ready for work or when about to leave work. Advice would be to avoid trying to force an idea, which often causes stagnation in creative pursuits. Allowing the ideas to fall into place on their own and being on the lookout for opportunities is preferable. As with many creative things like painting or writing songs or poetry, one improves at capturing concepts into cartoons as one keeps at it and the ideas begin to appear more often. Avoid feeling pressure to generate an idea and seek out fellow faculty's feedback to help to shape some weaker initial ideas. Getting the students involved in the creative process, asking them for suggestions or critiquing the images can help student engagement as will be discussed in the next section.

Image Creation Technique

When shown these cartoons colleagues often ask, "How long does this take you?" or "How did you make these?" Typically, it takes the author between 10 and 20 minutes to make a cartoon from blank sheet of paper to fully processed color image. Attempts to make them on a tablet directly seemed to stifle creativity since there seems to be more pressure to generate a finished product right away. Instead, an “old school” approach that begins with a pencil sketch on copier paper worked better for the author. The initial sketch usually begins with a light touch (so it can be more easily erased) and avoiding too much detail. This aspect is very important to the creative process, as the inspiration needs to be captured quickly and too much detail can be distracting. As previously mentioned, the simplicity of the characters greatly aids getting the sketch done quickly. When a sketch becomes satisfactory, a fine tip black pen (Prismacolor Premier 05) is used to trace only the lines worth keeping and after drying all the pencil lines are erased. A free smartphone scanning app (TurboScan^{TM} by Piksoft) is used to take a black and white picture of the paper. This app removes much of the gray areas including any pencil marks that weren’t completely erased, leaving a black and white image which can be emailed as a JPEG directly from the app. This image is imported into a PowerPoint file where it can be rotated a little if needed and its size expanded significantly. That PowerPoint file is used to store previous cartoons as well. The important “trick” in PowerPoint is to use Format>Corrections and select the preset to adjust the image to “Brightness: +20% Contrast: -20%” (Figure 12). The correction step in PowerPoint removes the small pixels around the black lines so when using the “fill” tool in Microsoft Paint, the colors fill nearly all the way to the edges of the lines.

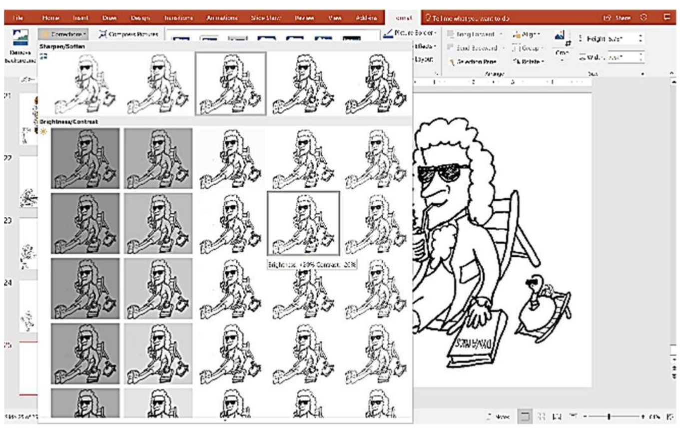


Figure 12: PowerPoint image Corrections.

The image is selected and copied/pasted into Microsoft Paint while also copying/pasting a previously colored cartoon into the same open Paint file to use the “Color picker” eyedropper tool to select the same colors as previously used. For instance, the brown and tan of Newtdog’s pants and jacket are not standard colors, so this process keeps them consistent. Thin lines in Paint using the pencil tool along with the color to fill a section can be used to enclose regions that aren’t completely closed, enabling them to be filled with the fill tool. Often there are images or shapes to incorporate with the cartoon drawing, and these can be resized in PowerPoint and pasted into the Paint file. Instead of twice drawing Newtdog’s body and the tree in Figure 9, that part of the drawing was copied and altered by cycling between PowerPoint and Paint to replace his head and the apple. The resulting image is cropped, saved as a JPEG and a copy placed in PowerPoint.

The appearance aspect may seem trivial, but a certain degree of "authenticity" of the cartoons can influence student acceptance. Some students have mistaken these cartoons for standard clip art which is testimony to the professional look achieved.

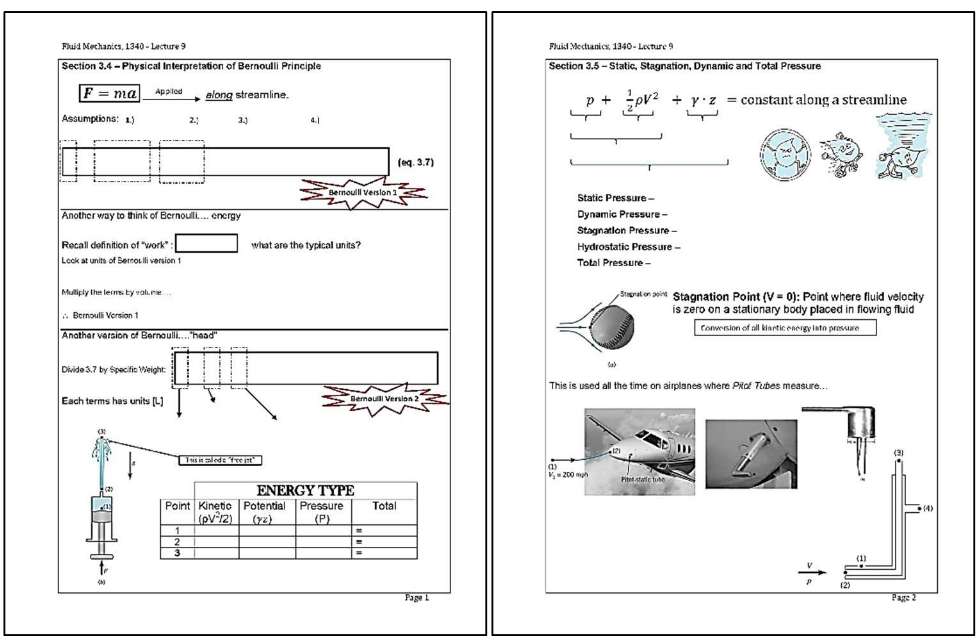
Classroom and Course Usage

As previously mentioned, these cartoons can be beneficial in three principal areas: concept mnemonics, classroom humor and sources for discussion. Methods for implementing them into the course to try to make them effective in these areas are described here.

Embedded in Course Notes

The author uses printable course notes that are provided to students on the course learning management system (LMS) and are an optional way for them to take efficient notes. The topic headings, textbook section numbers, simplified diagrams ready for annotation, blank spaces for derivations, boxes for important equations to be written (and book equation number), and example problem statements are provided on these notes. As part of this experiment to incorporate the cartoons into the courses, they were strategically embedded into the course notes. Figure 13 shows an example set of course notes for the Fluid Mechanics class that covers Bernoulli's equation and where the cartoons presented in Figures 6 and 7 were used.

In many classes, when the logistics of the room and podium computer allow for it, these course notes are turned into slides, splitting the top and bottom half of each page into one slide apiece. For classrooms with tablet type monitors, the notes slides are write on directly. The cartoons are also included as their own slides in larger form which provides an opportunity to briefly discuss/critique them with the class. The course notes and slides help keep the class organized and on pace.


Fluid Mechanics, 1340 - Lecture 9

Section 3.4 – Physical Interpretation of Bernoulli Principle

$F = ma$ Applied → *along* streamline.

Assumptions: 1.) 2.) 3.) 4.)

(eq. 3.7)

Bernoulli Version 1

Another way to think of Bernoulli.... energy

Recall definition of "work": what are the typical units?

Look at units of Bernoulli version 1

Multiply the terms by volume....

∴ Bernoulli Version 1

Another version of Bernoulli...."head"

Divide 3.7 by Specific Weight:

Each terms has units [L]

Bernoulli Version 2

This is called a "free jet"

	ENERGY TYPE			
Point	Kinetic ($\rho V^2/2$)	Potential (γz)	Pressure (P)	Total
1				=
2				=
3				=

Page 1

Fluid Mechanics, 1340 - Lecture 9

Section 3.5 – Static, Stagnation, Dynamic and Total Pressure

$$p + \frac{1}{2}\rho V^2 + \gamma \cdot z = \text{constant along a streamline}$$

Static Pressure –

Dynamic Pressure –

Stagnation Pressure –

Hydrostatic Pressure –

Total Pressure –

Stagnation point

Stagnation Point (V = 0): Point where fluid velocity is zero on a stationary body placed in flowing fluid

Conversion of all kinetic energy into pressure

This is used all the time on airplanes where *Pitot Tubes* measure...

(1) V_1 = 200 mph

(2)

Pitot-static tube

(1) (2) (3) (4)

Page 2

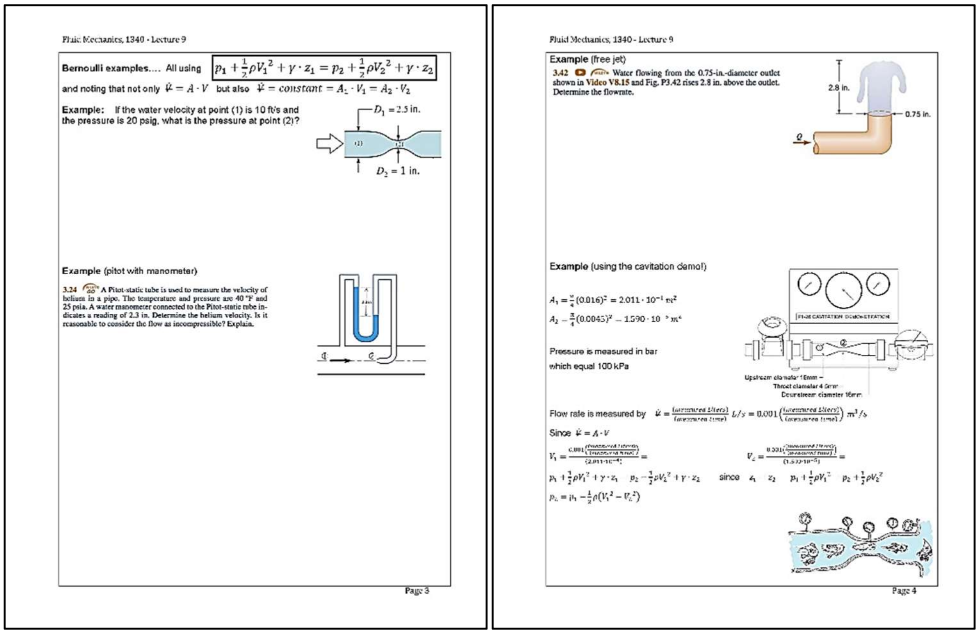


Figure 13: Example of embedded cartoons within course notes.

Featured on White Board Before Class

When a tablet podium was not available and when the classroom is not used in the period before, some notes and a quick version of the cartoon were written on the whiteboard before class. Figure14 shows an example on the day Buckingham Π and similitude were covered. This same cartoon also appeared on the LMS front page as discussed next. By giving the students a preview of an absurd picture on the LMS front page without explanation, the same picture greeting them when the come to classroom and wait for it to begin, and then revealing the meaning when class starts, may help to make the connection stick. In this case, "what is Buckingham Π used for?", the answer being "scaling" or "similitude". The absurdity of the pun between "pie" and "Π" also helps make this connection.

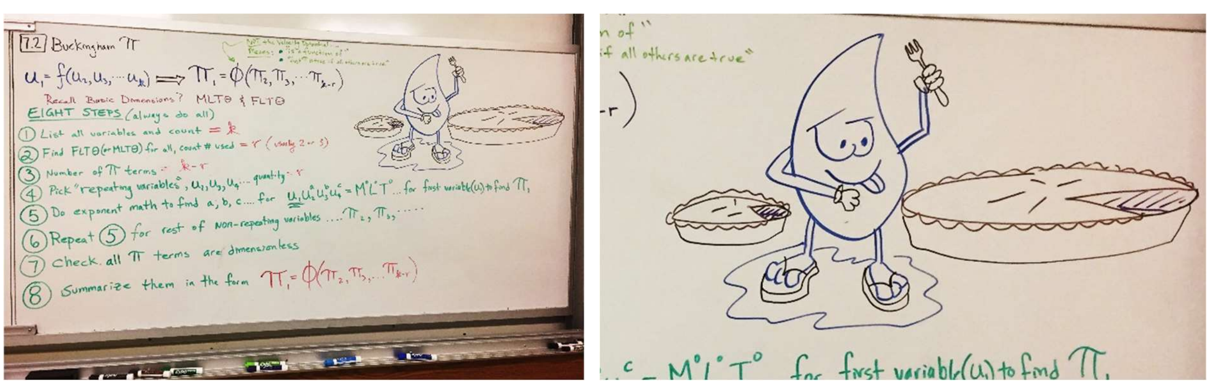


Figure 14: Buckingham Π similitude drawn on the white board before class.

LMS Front Page

The Learning Management System (LMS) can be used as the hub of the class, where students receive announcements, get the homework assignments, download the course notes, see the homework solutions and check their grades. With the introduction of each new topic, the students are greeted with the relevant cartoon on the front page. This helps make the characters sort of mascots for the course. As with the Buckingham Π cartoon there can be a bit of mystery as to the relevance of the cartoon. Letting them in on the joke in a delayed manner can help make them remember association last longer.

Not all the cartoons were created for pedagogical reasons. Humor can be useful to maintain good class-teacher report. Just before Thanksgiving Break Figure 15 appeared on the Fluid Mechanics LMS front page wishing the students an enjoyable break and including the suggestion "Be sure to tell your folks that the gravy is a non-Newtonian fluid (because of the corn starch in it)!".

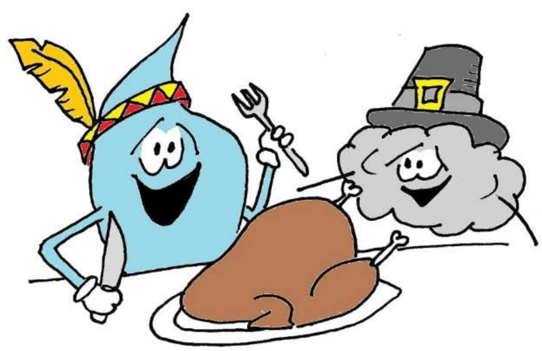


Figure 15: Thanksgiving and non-Newtonian gravy.

Similarly, before Spring Break Figure 16 appeared the Dynamics course LMS front page with the message "Have a great Spring Break and be sure to think about Dynamics the entire time...". While these messages have no mnemonical value, they are intended to serve a useful purpose. They send a somewhat subtle message: the students are part of the "engineers club" now which means they'll never stop being engineers, even during breaks.

Figure 16: Spring break in the sun with Dynamics book nearby.

In-class Discussions

As previously mentioned, many of these cartoons were created to help facilitate asking Socratic questions. It is not uncommon for students to freeze when a question posed by the instructor seems to be asking them to "read my mind". An example question in Fluid Mechanics is "why do you think sound travels faster in water than air?" They'll commonly answer, "because water is denser," but a preferred response is to identify the differences in vapor and liquid stiffnesses and make a connection to compressibility. By prompting them with hints to the answer with mention of the c-clamp cartoon (Figure 4), the students can arrive at this conclusion themselves.

Similarly, the cartoon can be the focus of a Socratic question. For instance, the image of Newtdog with a wheel barrow in Figure 17 can be used to ask about the definition of work as it relates to what he's doing. What part of the force and or what distance matters? How does this relate to the energy of the system? What if there is friction in the wheel barrow bearing?

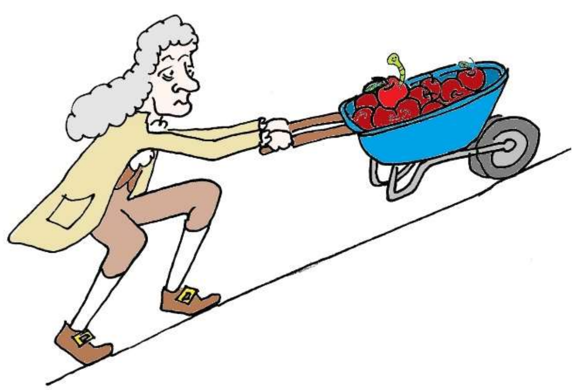


Figure 17: Newtdog performs work Sisyphus style.

Full disclosure, the author wasn't entirely pleased with this cartoon as a mnemonic and since the definition of work isn't completely apparent alone without explanation. This cartoon is more valuable as a thought provoking problem and for in-class discussion. This is also an opportunity for the class to offer suggestions on how to improve the image or make another one that would better demonstrate the “work is force through a distance” concept intended.

Response

Very limited student feedback was gathered at the end of the Fluid Mechanics course and none was collected after the Dynamics semester ended. Although an LMS survey was created in the Fluids course it was initiated after the final exam and the response rate was only three out of 60 students (divided between 4 sections taught by 2 instructors). The students had already completed the standard end-of-course survey, so it is perhaps understandable when they didn’t respond to the request to answer another after they were on holiday break. That limited response is included here because it exists, plus the three students are most likely some of the top performers as those are students who are typically most conscientious and complete every assignment.

True/false: *The cartoons were worth including in the course.* All three replied “true”.

Rate the usefulness of Wetted and Vapes as mnemonic devices. One student selected “Extremely helpful” and the other two “Somewhat helpful”.

For the remaining open answer questions, the question appears in italics with the response in quotations below.

Name (briefly describe) the cartoon that helped you the most (or just write N/A if none of them helped) and why. Response 1: “I enjoyed the streamlines picture the best but think the boundary layer graphic was the most helpful. It’s a hard choice because the great majority were helpful.” Response 2: “The boundary layer cartoon was the most helpful because it best showed what a BL looks like and how it forms.”

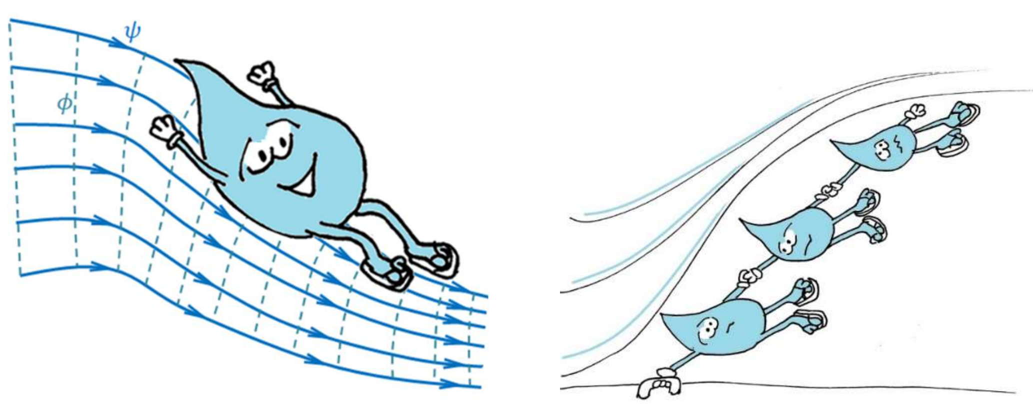


Figure 18: Cartoons mentioned in student feedback: Streamlines and Velocity Potential and Boundary layer formation.

In a brief sentence (or a phrase or word) describe your opinion of the teaching/learning benefits of using these cartoons in class. “These graphics added humor and a good mental picture of what we were going to learn about that day kind of preparing you for what was to come. Wetted and Vapes helped me visualize what was going on in the fluid on a particle level."

How can these cartoons or the use of them be improved to be more effective as a teaching/learning tool? "I guess using them more frequently would be best. They are creative and usually really help students with the lesson to come."

Ideas for future work are discussed in the conclusions section, but obviously better evaluation of the benefits of using cartoons for the purpose described here is needed.

Conclusions

This paper presented the author's experience using original cartoons in engineering classes. It is difficult to draw conclusions as to the mnemonic effectiveness of these cartoons without data on student concept retention, but the other benefits of the cartoons such as adding humor to the classroom, building good teacher-student report and encouraging discussion were easily observed by the author, who considers the experiment a success. Lessons learned, as in "I wish I'd done this better" and future work are described below.

Lessons Learned

The author first tried using cartoons in the Fall 2016 Fluid Mechanics class, and this seemed to work much better than the Spring 2017 Dynamics class. This can be attributed to a few elements, some within the instructor's control and others outside.

Firstly, in the author's opinion, there is a difference in attitude and receptiveness for first semester Juniors versus second semester Sophomores. The Sophomores taking Dynamics weren't nearly as interested in hearing about the cartoons as the Juniors taking Fluid Mechanics were. Additionally, it became apparent well into the semester that many of the Sophomores were unaware that their instructor was the one making these cartoons, as some students expressed surprise upon learning it and said they thought it was just some clip art being pasted into their notes. This seemed to change their receptiveness. The author apparently didn't realize he hadn't engaged in as much discussion about the cartoons with the Sophomores as he had when teaching the Juniors the previous semester. Also, the students being fully aware that the cartoons were actively being made (and just for them) created a more interactive experience. There was also a difference in the attitude of these particular grouping of students, where the Juniors were much more receptive to whimsical content than the Sophomores.

Measuring the usefulness of these cartoons was an afterthought, so an important lesson learned was to plan out a way to evaluate the benefits before the semester ended and the students dispersed. The end-of-course survey could have been modified to include questions about the cartoons which would have provided more student feedback data.

The author changed universities in Fall of 2017 and as of the writing of this article is midway through teaching Dynamics at the new school. Newtdog and Wormy are featured prominently, and a renewed focus on using the cartoons as catalysts for discussion has led to improved engagement, especially helpful with a new faculty member. There has been more cartoon discussion at the introduction of each new topic, and images such as the Polar and Path coordinate systems in Figure 5 have been alluded to repeatedly as part of answering student questions, especially the fishing reel and swivel stool in that figure. This reinforcement seems to have made the cartoons more meaningful.

Future Work

Several ideas have been suggested on how to use these cartoons or measure their effectiveness. Some of the most interesting involve getting the students involved in their creation and encouraging them to be creative. A student "suggestion box" discussion board on the LMS might be useful, so students can submit cartoon ideas or request the instructor draw particular concepts. Having the students draw their own cartoons as part of a project or for extra credit is an interesting proposal. Even those with limited artistic skills can draw stick figures with captions. An interesting potential benefit of this approach is that students will need to pick apart the concepts they're trying to convey in much more detail in order to come up a cartoon idea.

Evaluating the effectiveness of the cartoons is challenging and important future work. One proposal is to evaluate the students a semester or a year after they've completed the class. A survey or short "exam" that presents them with the images and questions what concepts are represented and what features of them are of conceptual significance. Alternatively, the delayed survey could be in two parts: first asking four or five relatively simple questions about what they recall about a Dynamics equation or concept, then a second survey that asks the same questions with the relevant cartoons next to them. The improvements in the answers (or lack of) can serve as a measure of whether and how effective the individual cartoons are as mnemonics for engineering courses to make the concepts stick.

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