Letters
to the Editor

Using Gravitational Analogies to Introduce Electric Field Theory Concepts – A response

I had applied similar analogies[1] in my physics classes for a few years; however, at one point I decided to modify the way I introduced them to students due to the following observation:

> *Although analogies were a great educational tool, students seemed to be overwhelmed by being introduced to them. I had the impression that students viewed these analogies as a new knowledge rather than a tool helping them comprehend new concepts.*

This observation prompted me to look closer into current physics curriculum, especially into concepts referred to as analogies in the sections on gravitation and electrostatics.[2]

Analyzing Table I, one can notice that gravitation does not contain many detailed concepts covered in electrostatics. A similar conclusion can be drawn from comparing potentials and potential energies in both chapters; students felt overwhelmed, because they were not exposed to concepts that seemed analogous.

In order to have the analogies work more effectively, I came up with the following conclusions:

- If section A is to be used as an analogy to teach section B, then the section A must contain all the types of concepts that section B does.
- Students need to practice analogy-type problems in section A in order to retain the knowledge and apply it in section B.

Table I. Forces and Fields; Summary of Topics in AP Physics Gravitation and Electrostatics.

Gravitation	Electrostatics
• Determine the force that one spherically symmetrical mass exerts on another.	• Determine the force that acts between specific point charges. • Calculate the magnitude and direction of the force on a positive or negative test charge. • Calculate the net force on a collection of charges in an electric field.
• Determine the strength of the gravitational field at a specific point outside a spherically symmetrical mass.	• Describe the electric field of a single point charge. • Use vector addition to determine the electric field produced by two or more point charges. • Define electric field in terms of the force on a test charge.

How to strengthen the parallelism between Gravitation and Electrostatics?

I made the following modifications to strengthen the correlation:

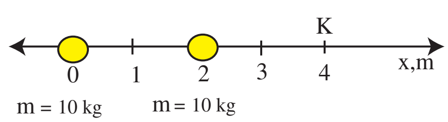
- I implemented additional types of problems in the section on gravity.
- While teaching gravity, I emphasized that similar concepts will be studied in the section of electrostatics.

This proactive approach established the foundation for correlation of the chapters and prepared the students for considering electrostatics as yet another application of already learned physics concepts. Below are examples of problems for Physics 1 and AP Physics that reflect these modifications.

Example

Two masses are placed in space where no other gravitational field exists.

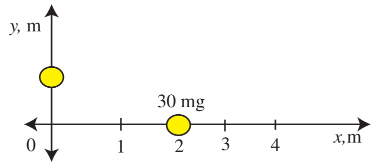
(Physics 1)



a. Calculate the net gravitation field at the point K due to these masses.

b. If an additional mass of 5 kg is placed at the point K, calculate the gravitational force exerted on the mass due this net field.

(AP Physics)



a. Calculate the magnitude and direction of the net gravitational field at (0, 0).
b. If a mass of 1 kg is placed at (0, 0), calculate the magnitude and direction of the instantaneous acceleration of the mass.

These problems can be reassigned in the section on electrostatics with masses replaced by charges. Another possible extension of this modification is asking students to predict the action of these fields (electrostatic and gravitational) on a combination of mass and charge.

Summary

It is apparent that the purpose of teaching physics is not exposing students to analogies but guiding them through the content. I believe that any approach that makes the subject more concise and integrated is worth trying in the classroom. With the discussed modifications, analogies became more meaningful to my students and furthermore, their understanding of electrostatics has been deeper since then.

1. Susan Saeli and Dan MacIsaac, "Using gravitational analogies to introduce elementary electric field theory concepts," *Phys. Teach.* **45**, 104–108 (Feb. 2007).
2. 2006 AP Annual Conference, Lake Buena Vista, FL, *Professional Development Workshop Materials,* College Board.

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Authors' Response

We agree and differ with Mr. Sokolowski regarding the role of analogy in physics learning. Yes, analogies are knowledge in and of themselves apart from the examples, and analogies initially demand additional student effort or *cognitive overhead*.[1] Each classroom teacher is most familiar with the needs of his/her students and the classroom curricular goals; the teacher must decide when, where, which, at what level of complexity, and even with which individual student the use of analogy is appropriate.

Much research indicates that the use of analogy in conceptual learning is almost certainly unavoidable, and we particularly disagree with Sokolowski's contention that section A must be complete before teaching section B via analogy. We believe that the pedagogical power in using physically analogous situations is due to the fact that analogies are *not* identical situations; analogies are always only *approximately* similar and serve to promote the development and illustration of abstract models. A perfect and complete analogy would be a *tautology,* of no pedagogical power whatsoever. The processes of creating abstract models and visualizations by recognizing and mapping features between different phenomena and problems lie at the heart of how science is done (and how individuals conceptually learn). Moreover, this procedure flows back and forth so that meaningfully learning section B inescapably reinterprets and enlarges the models constructed by students when they learned section A. So it often makes sense for an instructor to introduce a new idea in section B simply due to pedagogical constraints and then map backwards into section A. This is typical of how physics majors learn about Gauss' law while constrained by mathematics courses: first for electrostatics, then later for gravitation.

The analogies presented in our paper are keyed to some of the most powerful unifying ideas in physics—invoking and visualizing field theory, geometrical symmetry, and conservation laws—and these powerful ideas do reflect physics content that is usually (at least implicitly) part of introductory physics. Thus, these analogies do much more than simply link specific individual problems and phenomena often studied in introductory courses; these analogies (hopefully) re-illustrate unifying ideas quite apart from the individual problems and phenomena. Again, the classroom teacher is the most informed person on the scene and must decide how and when to use whatever pedagogy—not all students might benefit from gravitostatics exercises at the expense of the analysis of gravitational field inside a theoretically hollow Earth, or of an electrophorus.

Because of their complexity, analogies don't readily lend themselves to standardized testing. While we recognize that these analogies may very well not be your tested content, we believe our analogies are in fact at the very heart of introductory electric and gravitational forces.

1. J. Clement, "Imagistic processes in analogical reasoning: Conserving

transformations and dual simulations," in P*roceedings of the 26th Annual Conference of the Cognitive Science Society.* (Erlbaum, Mahway, NJ, 2004).

2. C. Camp and J. Clement, *Preconceptions in Mechanics: Lessons Dealing with Students' Conceptual Difficulties* (Kendall/Hunt, Dubuque, IA, 1994).
3. J. Piaget and R. Garcia, *Psychogenesis and the History of Science*, translated by H. Feider, (Cambridge, NY, 1989). C.f.: Chapters 1and 2, pp. 30-87.
4. S. Saeli and D. MacIsaac, "Using gravitational analogies to introduce elementary electric field theory concepts," *Phys. Teach.* **45**, 104–108 (Feb. 2007).

Dan MacIsaac and Sue Saeli

Thinking Some More About Bernoulli

Thank you to Martin Kamela*1* for reinforcing the fact that faster-moving air does not necessarily have a reduced static pressure (i.e., that faster-moving air does not necessarily push less in a sideways direction). However, I have reservations about both explanations provided for the phenomenon shown in his Fig. 2. His first explanation invokes the concept of action and reaction, but I cannot see that it is a valid application of this principle. Kamela does not identify the action or reaction forces, and I do not understand what "the reaction force pulls up on the air inside the medicine dropper" (p. 380) could possibly mean. Indeed, I cannot see that Newton's third law provides a useful framework for explaining this phenomenon, but would welcome being shown how it can.

In his second explanation, Kamela uses Bernoulli's principle. While I find Bernoulli's principle to provide a satisfying explanation of phenomena involving fluids passing through a constriction (e.g., blowing through a funnel containing a table tennis ball and finding that the ball is not forced from the funnel), and consider Kamela's description of his Fig. 2 situation to be fine, I don't think it is obvious—especially to the casual observer—that Bernoulli will be applicable here; that is, it is not obvious that the streamlines will be squeezed closer together, or bend downwards, as the air flows across the end of the medicine dropper. Rather, I wish to suggest that the idea of entrainment of air, as described in Eastwell[2] and which actually takes into account the viscous effects that accompany the interaction of a moving stream of air with a stationary air mass, provides a more concrete, obvious, and hence better cause-and-effect explanation for Kamela's Fig. 2 situation. This paper also shows how Bernoulli's principle can still be considered to be "at play" in such situations, but more in a secondary sense than in terms of providing the best cause-and-effect explanation. Entrainment of air can also be used to better explain Kamela's other example of a ball being levitated in an airstream, and is indeed necessary to explain what happens in situations involving moving air where I cannot see that Bernoulli is helpful, such as when a straw is used to blow air beside a candle flame and the flame is observed to bend toward the airstream.

1. Martin Kamela, "Thinking about Bernoulli," *Phys. Teach.* **45**, 379–381 (Sept. 2007).
2. P. H. Eastwell, "Bernoulli? Perhaps, but what about viscosity?" *Sci. Educ. Rev.* **6**, 1-13 (2007); http://www.ScienceEducationReview.com.

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Author's Response

Peter Eastwell makes good points. The description of Fig. 2 in Ref. 1 in terms of Newton's third law can be better phrased, and entrainment of air complements the understanding of the demonstration.

The roughly semicircular path of air volume element over the tube in Fig. 2 necessitates a net downward force. This means that the force from above must be greater than the force from the still air in the tube pushing up on the moving volume element. The reaction force pushes down on the still air in the tube. The observed "pulled up" level in the figure can be understood by considering the difference between the reaction force and the force from atmospheric pressure acting on the other side of the manometer.

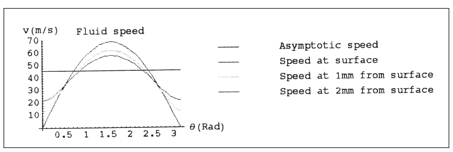
Entrainment of air is the effect by which the boundary layer of air is pulled in with a jet and it is the reason why slowly moving air follows the shape of obstacles, such as airfoils.

As the air stream moves over the tube in the demonstration, air in the tube is drawn into the stream. The reduced pressure in the tube results in the stream following roughly the shape of the obstacle.

Entrainment can also improve the understanding of the stability of the ball levitating in a jet. Air follows the surface of the ball. For an off-centered ball in a jet, the shedding of streamlines in the outward direction forces the ball (via Newton's third law) to remain centered in the air stream.

The idea of entrainment of air is important and I agree it should be introduced with the discussion of fluid flow. However, let me try to convince the readers that Bernoulli's equation is still applicable in the demonstration. I measured the speed of airflow from the blower, at the distance of the glass tube, to be about 46 m/s. The correlation of fluid speed with pressure, from Bernoulli's equation, implies the flow should increase in speed to about 53 m/s at the top of the glass tube to agree with the manometer observation (Figure 2).[1]

Consider the velocity field for potential flow around a sphere,[2] assuming this simplified model helps explain what happens in the demonstration. Plotting the speed profile for the fluid, as a function of the angle, we note that 53 m/s needed to account for the observed pressure is not unreasonable.



1. Martin Kamela, "Thinking about Bernoulli," *Phys. Teach.* **45**, 379–381 (Sept. 2007).
2. A.B. Bhatia and R.N. Singh, *Mechanics of Deformable Media* (IOP Publishing, Bristol, 1986), Section 11.3; and T.E. Faber, *Fluid Dynamics for Physicists* (Cambridge University Press, 1995), Section 4.7.

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Defusing Classroom Situations

Professor Milner-Bolton has the right idea ["Teachers as actors," *Phys. Teach.* **45**, 459 (Oct. 2007)]. The teachers I remember most were showmen. There was no sleeping in their class.

May I add a related item. Students sometimes eat in my class. Many of them work part- or even full-time, and they carry a full load of coursework. There's just no time for formal dining. So I don't object. But occasionally it can become annoying.

When that happens I don't say anything, but at the next occurrence I come prepared. I spread out a white tablecloth in front of the student, together with silverware, colorful paper plates, even a small bottle of wine. This usually cracks up the class, but equally important, it effectively puts the other students on the teacher's side. The offending individual usually gets the hint and finds another place to eat.

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Which Way Is Clockwise?

The Guest Editorial "Teaching Physics in the Digital Age," by Dr. Matthew Vonk (p. 532, Dec. 2007), brought back to memory an incident in one of my classes several years ago. The clock I "scrounged" to use in my classroom came from an old telegraph office in Lexington, Ky. It was large, ran on standard ac with a synchronous motor, and had a backup spring to allow it to run and keep time when the power was often interrupted during this era. When first plugged in, a little knob on the back had to be twirled to start it. I supposed the inventors had not discovered shaded pole motors in the late 1800s or early 1900s. It just so happened that the little knob could be twirled either way and the clock would politely run backward or forward. So, I made another face with numbers in reverse and would change the clock direction every few days just as a novelty. After all, time is relative. One day, during a test on electromagnetic fields, a student quietly came up to me and said, "Mr. Evans, which way is clockwise? My father is an electronic engineer and everything in our house is digital. Furthermore, I never know which way your clock is going to go." I proceeded to draw a circle on a piece of paper for him with appropriate labeled arrows, and he returned to his seat while I mulled this incident over for a while. Times are a changin'!

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