**A physical model using a Lycra® sheet for teaching**

**gravitational and electric fields in introductory physics**

Justin L. Snook

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State University of New York College at Buffalo

**Abstract:** *Newton’s law of universal gravitation* is typically presented with an emphasis on its mathematical formalism. For example, through the inverse-square relationship between two objects’ spatial separation, *r*, and the gravitational force they exert on one another, namely *F = GMm/r*2. Often the derivation is given to students with little experimentation to determine the relationship between the variables, i.e. *M*, *m*, and *r*. However, a Lycra® sheet can provide a physical model for gravitation and a means to demonstrate the nature of gravity, visually representing the distortion of the field around a mass. In this paper, I will discuss several of the activities and lessons to develop the Lycra® Sheet Field Model of the gravitational force and then extend the model to demonstrate gravitational field and potential. Finally, I will extend the lessons to model the analogous nature of the electric field.

**Introduction**

This paper is devoted to applying both model-centered instruction[[1]](#footnote-1) and lecture demonstrations[[2]](#footnote-2) in teaching field force concepts. I introduce the Lycra® Sheet Field Model as a physical model for gravitational fields. The model is patterned after the space-time fabric in Einstein’s theory of general relativity. The Lycra® sheet provides a visual representation to describe the effect of an object on the space around it. Once the model has been fully developed for gravitation, it then becomes an analogous model for the electric field. This paper describes how the Lycra® sheet might be implemented in the curriculum for an introductory physics class.

**Background**

There few applications of the relativistic model of gravity in the classroom. Gravitation is generally taught as proclamations of relationships using mathematical models. While the space-time fabric model is the accepted model of reality, most curricula still emphasizes Newton’s Law of Universal Gravitation to describe the gravitational attraction. The few lessons and activities involving the space-time fabric are included solely in modern physics curricula. However, I suggest introducing the space-time fabric model when the concept of gravity is first introduced. In the modeling–instruction materials (Hestenes, Swackhamer, & Dukerich, 2004), universal gravitation is included with the central force particle model, which is both common and fitting when discussing the generalized orbital motion of satellites. However, the Lycra® Sheet Field model provides an excellent opportunity to develop a conceptual model of gravity. The model can still be included in the central force particle model unit, but should be fully developed.

Traditional instruction of the electric field generally involves many demonstrations of electrostatic phenomenon, after which Coulomb’s Law is stated by means of the (accurate) observations of the phenomenon. However, as found by Miller, Lasry, Chu, & Mazur. (2013), knowing the underlying concepts before the demonstration performance is essential for conceptual change. Typically, students in introductory physics classrooms do not have the background or experiences with the electric field concepts to make meaningful predictions about the interactions. Students have been taught in lower grades’ science classes that “opposite charges attract”, however, they can seldom provide insight into that expression.

**Student beliefs about Gravity**

Student beliefs, or preconceptions, about gravity were researched by Williamson and Willoughby (2012) They uncovered four common student gravitational preconceptions, the most recurrent being the “Boundary Model” where the effects of gravity diminish rapidly or disappear completely, which leads to the belief that there is no gravity in space. Williamson, et al. also found the documented beliefs that gravity is associated with other forces, like magnetism, rotation, and atmospheric pressure. Watts (1982) studied student ideas about the force of gravity, which are contradictory at times. Both Watts and Williamson, et al.’s (2012) found that students believe gravity “requires a medium to act through”, like the atmosphere, and an absence of the medium indicates there is no gravitational attraction. In addition, Watts found that students believe gravity is “selective”; it does not affect objects that are at rest, like when sitting on a shelf, or when projected into the air. Palmer (2001) investigated student alternative conceptions of gravity. He found that students are not consistent in the way they apply their beliefs about gravity. Which belief they apply is context-dependent, meaning that the physical features of the task or problem determine how the student applies their concepts. Students often believe that gravitational attraction is only an earth bound event; gravity did not exist outside the earth’s atmosphere. An object will float in space because it is in a vacuum.

**Traditional instruction about gravity**

Traditionally, instruction of gravitational concepts has followed a historical approach. Most college level textbooks generally use this sequence, starting with Kepler’s Laws and then proceed to discuss Newton’s use of these laws, which are based on observation, to derive, whereas the conceptual relationships are generally stated. On the other hand, high school textbooks seldom devote a whole chapter to gravitation. Instead, the textbooks often include gravitation with the chapter on uniform circular motion. Research done by Baldy (2007) has shown that the traditional instruction of gravitation, based on force concepts as action on an object, is highly ineffective. The traditional approach “does not take into account the students’ initial conceptions, which are often incompatible with scientific knowledge” (Baldy, 2007). Students are capable of learning the formula, remembering and reciting it, but lack conceptual understanding of the physical phenomenon.

There have been a few attempts to reform gravity instruction. For example, *Lecture tutorials for introductory astronomy*, (Prather, Slater, Adams, & Brissenden, 2008) includes proportional reasoning and agree/disagree and explain problems instead of the general plug-and-chug type questions. The questions in the tutorial focus on the mathematical representation of the Law of Gravity. Additionally, Baldy (2007) suggests using Einstein’s model to show the deformation of the space-time fabric around an object with mass.

**Preconceptions about Electric Force and Fields**

Current curriculum gives students little experience with electrostatic phenomena. A student’s experience of static electricity comes from their observation of static cling, static electric shock, charging a rubber balloon by rubbing it against their hair, etc. Young children are told by their parents that “opposites attract” without being given any explanations. Therefore, the abstract electrostatic concepts are difficult for students to assimilate and understand (Arons, 1997).

Students learning about electrostatic phenomenon are able to use terms such as “electric charge,” “like charges,” “unlike charges,” “electric current,” “potential difference,” etc., but cannot give concrete meanings to describe the words as they use them. Students will often ascribe the electric force interactions to another force, like gravitational or magnetic. Interestingly, these other forces are also field forces that do not require physical contact of objects.

**Traditional Instruction of Electric Force and Fields**

Traditional instruction of the electric force and electric field is often taught after mechanics topics and most students do not see a connection between the topics. Teaching electrostatic concepts in introductory physics typically involves demonstrating the interactions of charged objects, either by attraction of oppositely charged objects or the repulsion of similarly charged objects. For example, research by Chang (2011) incorporating interactive demonstrations of electrostatic phenomena during instruction has shown to increase performance on post-test scores compared to those of traditional modes of instruction. While the demonstrations center on applications of electrostatic principles, the relationship between charged objects is generally given to the students and, like gravitation, many times does not include a physical model demonstrating the reasons for the interaction. Because the mathematical relationship is analogous to universal gravitation, the Coulomb’s Law equation is generally stated. This is usually followed by identifying the analogy to Newton’s law of gravitation and comparing the relative strength of the respective forces, as suggested by Arons (1997). An excellent example of using the gravitational–electric force analogy is included in *Workshop physics activity guide: Module 4: Electricity and magnetism* (Laws & Boyle, 1997, pp. 574 – 592). In the lesson, each of the electrical concepts are first developed with the gravitational analogy. The tutorial includes Gauss’ Law, which may be omitted for non-calculus based courses. The techniques used by the workshop activities were influential in determining how the model is developed for the electric field.

When using the Lycra® Sheet Field Model instruction, the gravitational–electric field analogy develops naturally. Students have an environmental experience with gravitation and the concepts have been fully developed by their experience. Each concept has already been introduced in terms of the gravitational field, and the difficulties the students generally have with the nature of the electric field dissipates. The abstract and foreign concepts that students typically struggle with do not affect student learning. Instead of seeing something new and unrelated to mechanics, students see electric concepts as an application of the Lycra® Sheet Field Model. Instruction with the Lycra® Sheet Field Model to teach electrical concepts becomes a spiraling activity and an opportunity to review concepts.

**The Lycra® Sheet Field Model**

The Lycra® Sheet Field Model is introduced as a physical model of gravity that is patterned after Einstein’s theory of the space-time fabric. The Lycra® sheet can be purchased at any fabric store. It is recommended that the fabric contain about 20% spandex, which gives it a considerable amount of stretchiness. The sheet should be large enough to be easily manipulated and visible to the whole class; a 4.5’ x 4.5’ sheet is a good size to meet these requirements. The sheet will be slightly stretched, adding a slight tension to the sheet to make it a flat, horizontal surface. Some teachers have constructed a circular frame to attach the sheet for support, where students line up around the frame to hold it and to observe the demonstrations. Other teachers have just used the students to hold on to the sheet and stretch it manually. This allows the students to feel the pull on the sheet during the demonstrations.

When an object, like a small medicine ball, is placed on the fabric, the mass causes the fabric to stretch as it moves closer to the ground. However, due to the nature of the spandex in the sheet, the slope of the sheet is not constant. In fact, the shape of the sheet and the graph of the gravitational field strength versus the distance from the object have a similar shape. Therefore, the sheet provides a sufficient model of the gravitational and electric field. The changing of the shape of the sheet by the mass of the object represents the distortion of the space-time fabric. The Lycra® Sheet Field Model, therefore, is a model that agrees with modern, relativistic theory.

The use of a physical model to represent the gravitational field, and later the electric field, enables the student to make personal prediction and observations about the nature of the field. Through their observations and discussions, students can reject the common misconceptions discussed previously. Students may observe that the field is not a localized phenomenon. Rather than having a boundary, students should determine that gravity reaches to infinity. By demonstrations applying the Lycra® Sheet Field Model, students can see that it is the interactions of these fields that cause objects to be attracted toward one another. If the curriculum requires instruction on Kepler’s Laws (like in the AP Physics C course), the teacher could use the motion of orbiting objects around a massive object using the Lycra® Sheet Field Model. However, in this case, it should be noted that the Lycra® Sheet fails to show exactly the continuous motion of the orbiting object due to the friction of the sheet on the object. The teacher should make sure to point out the limit of the model in this application.

The Lycra® Sheet Field Model should be introduced briefly at first, perhaps by showing the gravitational field and stating that the slope of the sheet represents the field. Spiraling back to the sheet at specific points in the curriculum is important to developing conceptual knowledge of fields. Each time the sheet is used, a review of the parts of the model should be done, followed by new components of the model. By the end of the gravitation unit, the student should know all the characteristics of a field from the Lycra® Sheet Field Model.

Using activities and demonstrations to show the interaction between electrically charged objects is important for students. Students need to be able to observe that the interaction does not require physical contact in order for the force to be applied. Without the teacher telling them, students should be able to recognize the similarity to gravitational attraction. They should notice that the closer the charged objects are, the greater the electric force is acting between the charged objects. This observation may remind them of the gravitational field relationship. At this point, students can return to the Lycra® Sheet to review the gravitational field concepts. Ideas like the deformation of the sheet, the relative strength of the field, represented by the slope of the sheet, at different locations on the sheet, and the shape of the field lines should be among the concepts reviewed. This action renews the context for the students and focuses their thinking on applying the model to a new situation.

**Curriculum Guide**

# **Overview**

The Lycra® Sheet Field Model is intended to be used with many of the activities form the Modeling Curriculum developed by Wells, Hestenes & Swackhammer (1995) and available at the American Modeling Teachers Association website. The model is developed across multiple topics related to gravity. It is briefly introduced with qualitative observations of the shape of the sheet and related to the weights of objects. Student observations are reviewed during lessons on universal gravitation and the model is fully developed. The model is extended to develop the electric field concepts. By using the Lycra® Sheet Field Model, students are given a tool that they can use to think in terms of the field, potential, or both. Students should be able to explain field concepts and use the model in their problem solving.

# **Sequence**

**Gravitational Field Instruction**

**Introduction of the Lycra® Sheet Field Model**

# Spring scale lab and discussion (weight and mass)

1. Introduce Lycra® Sheet Field Model (LSFM) via lecture-demonstration

**Universal gravitation with Lycra sheet [after energy model and commonly during CFPM]**

1. Review of LSFM demonstration
2. Introduce Field lines and Newton’s universal gravitation
3. Modeling universal gravitation activity and PhET simulation and discussion (Appendix C)

**Energy of the Gravitational Field**

# Activity: defining potential

# Demonstration – Lycra® Sheet and Gravitational Potential

# Gravitational Potential worksheet

# Lab/demo/discussion: topographic maps

**Electric Field Instruction**

**Lycra® Sheet Field Model and the Electric Field**

**Electric field interactions between charged objects**

1. Activity - Sticky Tape and worksheet 1
2. Lab – Coulomb’s Law: The Repulsive Balloon and worksheet 3– Coulomb’s Law
3. Class activity - Introducing the Electric Field
4. Electric field due to a dipole part 1
5. Worksheet 4 – Drawing the Electric field
6. Electric field due to a dipole part 2
7. Worksheet 5 – Electric Fields
8. Other arrangements of charge

**Energy of the Electric Field**

1. Review: Lycra® Sheet Field Model for gravitational potential
2. Lycra Sheet Field Model – Electric Potential of a uniform field
3. Whiteboard page 2 of worksheet 1 – uniform fields
4. Lab: Mapping electric potential
5. Lycra Sheet Field Model – Electric Potential of a non-uniform field
6. Worksheet 2 – potential in non-uniform fields
7. Other charge distributions

# **Instructional notes**

**Gravitational Field Instruction**

# **Spring scale lab and discussion (weight and mass)**

From modeling curriculum – Mechanics Unit 3 Free particle model available at

www.modelinginstruction.org

1. **Introduce Lycra® Sheet Field Model (LSFM) via lecture-demonstration**

* The Lycra® Sheet Field Model is first held flat by the students that are lined up along the edges of the sheet (See Figure 1). Students are told that the sheet represents a region of space. When there is no object within that region of space, that field is undisturbed.
* Ask for predictions about what would happen if an object, like lightweight medicine ball, would be placed in the sheet. Allow students time to discuss with their group members and record their predictions on a whiteboard to share with the class.
* Place the ball in the center of the sheet and guide students in a discussion of their observations (Figure 2 and Figure 3).
* Students should observe:
  1. The slope of the sheet is very steep near the ball and decreases rapidly as you move away from the ball.
  2. The sheet has a non-zero slope, even if it is very small, at every point on the sheet.
  3. The slope of the sheet at the same radial distances from the ball are identical.
* Remove the ball and show the students a heavier ball. Ask for predictions about how it will compare with the first when placed on the sheet. Place the second object on the sheet and discuss observations. Students should observations:

1. The object with more mass deformed the sheet more than the less massive object.
2. The sheet has the same general shape regardless of how much mass the object has.

Note: These observations will be important when discussing Newton’s law of universal gravitation. However, a simple statement of these observations is sufficient at this point.

**Post Demo discussion**:

* The slope of the Lycra® sheet represents the strength of the field. An object will deform the space around it and create a gravitational field.
* The gravitational field is greatest near the object, causing the sheet to have the greatest slope near the object. If you examine the slopes at different distances away from the object, the sheet has different slopes, decreasing with greater distances.
* The sheet never remains horizontal, or with a zero slope, even if extended to infinity. The slope of the sheet at the same distance from the object always has the same magnitude. This observation relates to the investigation of weight versus mass of objects (Activity 1). Since all the measurements were taken at virtually the same distance from the object (the earth), the slope of the sheet, and therefore the strength of the gravitational field, is the same value, approximately 10 N/kg.
* The weight of an object is the product of the gravitational field strength and the mass of the object where is the slope of the sheet at that point. Students can then determine the weight of an object with a known mass if they knew the value of the field strength at any point around the object.

**Universal gravitation with Lycra sheet** [after energy model and commonly during CFPM]

1. **Review of LSFM demonstration**

* Set up the Lycra® sheet as before with students holding the outside of the sheet and a ball in the field to represent an object, i.e. the earth. Guide the students in a review of the gravitational field concepts developed so far. Specifically students should be able to relate:

1. An object deforms the field surrounding it, the more mass it has the more the deformation.
2. The slope of the sheet represents and it is smaller at greater distances from the object.
3. Near the earth, and points towards the center of the earth.
4. The weight of an object is calculated by using the approximation.

Note: In the previous lessons on the force of gravity, discussions were of near-earth conditions, where the field is relatively constant. The lessons in this unit will examine the field far from the earth, and other objects.

1. **Introduce Field lines and Newton’s universal gravitation**

* Show a second ball of equal mass to the class and solicit predictions from students about the effects of placing it on the sheet at a different location on the sheet and released. Students share their predictions.
* Place the second ball on the sheet and ask for observations. If performed properly, the masses should move towards one another. Remove the second mass and repeat the demonstration two additional times with a smaller second mass each time. Students discuss how the three demonstrations are similar and the effect of the mass on the attraction of the objects. Observations should include:

1. The attraction is proportional to the mass of the objects – more massive object have a stronger attraction.
2. The attraction is inversely proportional to the distance separating the objects – objects that are closer have a stronger attraction.

* Remove all objects from the sheet so it is flat (slope is zero). Ask the students to operational define how to determine the presence of a gravitational field and allow them to work on it with their group members.
* Students share their definitions with the class and the class agrees on a single definition.
* Using what they observed from the first demonstration in this unit, the definition should include:

1. An object placed in the field would feel an attraction, a force that causes it to move toward a second object (Figure 4).
2. The test mass should have a very small mass compared to the first, like a table tennis ball, so it does not distort the field it is in.

* Students use chalk to draw the direction of the force on the test mass at various locations in the field and at different distances from the source of the field. They should see that the force is greater near the object and decreases as you move away. When this is done at all points in the field, the standard map of the gravitational field is generated on the sheet.
* Students should observe that the force vectors converge radially, indicating an attraction that they observed in the first part of the demonstration.
* Guide students to the drawing the field lines on the sheet using chalk. The field lines converge on the ball (Figure 5).
* A conceptual introduction to Gauss’ Law and flux is discussed. Ask the students for a description of the gravitational force using the shape of the field lines.

1. **Modeling universal gravitation Activity and PhET simulation and discussion** (Appendix C)

This activity is an investigation to determine the quantitative relationship between the masses and the separation of the objects. The students use a simulation at the PhET website (http://phet.colorado.edu/en/simulation/gravity-force-lab). In this two part investigation, student are able to manipulate: 1) the values of two masses and 2) the separation of the objects. Students take data for each part and generate a graph, linearizing if necessary, define the relationship and a mathematical model for the data, and calculate the slope of the linearized equation. This activity leads the students to develop Newton’s universal gravitation relationship and derive the Gravitational constant, G, from their recorded data. After the students perform the investigation, they write their results and conclusions on a whiteboard and share with their classmates. Students should be able to define the general expression for the gravitational field strength, , using the relationships they have just discovered.

1. **Newton’s Law and Gravity Tutorial**

Available from *Lecture-tutorials for introductory astronomy* (2nd ed.) (pp. 29 – 31). San Francisco: Pearson Addison-Wesley.

The tutorial is an alternative to a worksheet on universal gravitation problems because it employs proportional reasoning and agree/disagree/explain problems instead of the general plug-and-chug type questions. The questions in the tutorial focus on the conceptual understanding of the Law of Gravity.

**Energy of the Gravitational Field**

# **Activity: defining potential**

From modeling curriculum – E&M Unit 2 Potential available at www.modelinginstruction.org

# **Demonstration – Lycra® Sheet and Gravitational Potential**

* Students again hold the sheet flat and a ball is placed in the sheet to create a gravitational field. Have the students redraw the gravitational field lines on the sheet in chalk.
* A student selects a point on the sheet close to the ball and marks it with chalk. The chalk is passed to other students around the sheet to mark on the sheet points that have an equal potential as the first mark. (For a ball, the marks should be equal distances from the ball along different radial lines and form a circle around the object.) If there are any points that are not expected, a discussion by the students should occur to verify the validity of those points.
* Choose a second point at a different distance from the ball. Ask the students the shape of the equipotential surface that would include that point. Give the chalk to four or five different students to each draw an equipotential surface, creating a contour map.
* Remind the students that the slope of the sheet is the gravitational field. Ask the students about what would represent the gravitational potential. (The "height" of the sheet, the vertical distance the sheet has moved from the horizontal, flat sheet, at a point represents the gravitational potential at that point.) The gravitational field lines will always cross perpendicular to the equipotential surface
* Reiterate that gravitational potential, like the field, is a property of the space and does require an object to occupy the position in the gravitational field. The space is gravitationally deformed by the presence of an object within that region of space.
* Define the mathematical relationship for the field around a circular object, and in general the gravitational potential (*y* – axis) is the product of the field (the slope) and the position along the *x* – axis of the object.
* Use the sheet and the test mass to discuss with the students the requirements for doing work on an object in a gravitational field.
  1. If there is work done on the object, it will move to a different potential surface. If the field does work, the object will move to a lower potential that is closer to the source. If an external force does work on the object against the field, the object will move to a higher potential surface.
  2. If the object does not have a change in gravitational potential, work done on it is zero.
  3. An object can move around the potential surface without changing its gravitational potential energy.

# **Gravitational Potential worksheet**

# From modeling curriculum E&M Unit 2 Worksheet 1 page 1 available at www.modelinginstruction.org

# **Lab/demo/discussion: topographic maps**

# From modeling curriculum – E&M Unit 1 Potential available at www.modelinginstruction.org

**Electric Field Instruction**

**Lycra® Sheet Field Model and the Electric Field**

**Electric field interactions between charged objects**

1. **Activity - Sticky Tape and worksheet 1**

# From modeling curriculum – E&M Unit 1 Charge and Field available at www.modelinginstruction.org

1. **Lab – Coulomb’s Law: The Repulsive Balloon and worksheet 3– Coulomb’s Law**

# From modeling curriculum – E&M Unit 1 Charge and Field available at www.modelinginstruction.org

1. **Class activity - Introducing the Electric Field**

* Lead a discussion summarizing the lessons learned in the first two activities and worksheets. Students should note that:
  1. the interaction between the sticky tapes do not require physical contact in order for the force to be applied.
  2. the closer the charged objects are, the greater the electric force is acting between the charged objects.
  3. the force between charged objects is approximated using Coulomb’s Law

, where k = 9.0 x 109 .

* 1. the interaction is the effect of an electric field that is similar to the effects of the gravitational attraction.
* Return to the Lycra® Sheet to review the gravitational field concepts. Ideas like the deformation of the sheet, the relative strength of the field, represented by the slope of the sheet, at different locations on the sheet, and the shape of the field lines should be among the concepts reviewed. This action renews the context for the students and focuses their thinking on applying the model to a new situation.
* With the sheet flat, discuss the differences between the gravitational field and the electric field. The gravitational force is always attractive, always drawing masses together. Demonstrate that the distortion of the field is always down. Press down on the sheet with a moderate amount of force. At a different position on the sheet, press down more firmly to show that a more massive object will cause a greater depression in the sheet (field).
* Discuss how to model the fact that an object can have more than one kind of charge – positive or negative. While all gravitational deformations of the field produces wells in the field, electric fields can produce a well or an “anti-well”, or “witches hat”, that goes upward.
* Demonstrate on the Lycra® sheet. If a charged object creates a well, the opposite charge can be positioned on the bottom of the sheet and pushed upward to create an anti-well.
* Follow the procedure for creating the gravitational field line for a positive charge using a test “charge” and again for a negative charge. Discuss reasons for the use of a test charge that is both small and positive by convention.

1. **Electric field due to a dipole part 1**

* Demonstrate two oppositely charged objects by using two balls, creating a well and anti-well deformation on the sheet. Using a table tennis ball as a test charge, students draw the force on the test charge on the sheet from one charged object and then the second. Ask students about the relative magnitude of these forces and the resultant of these forces produce the direction of the field line at that position.
* Place the test charge on the sheet at the position and release to show that the direction it travels when released is the same direction as the net force at that position in the field. Make a point that these vectors re not the field lines, but are tangent to the field lines at that point.

1. **Worksheet 4 – Drawing the Electric field**

# From modeling curriculum – E&M Unit 1 Charge and Field available at www.modelinginstruction.org

1. **Electric field due to a dipole part 2**

* Set up the dipole arrangement. Students compare their drawn field lines with the slope of the sheet. Ask the students to locate a point on the sheet where the electric field has a zero value. Students should conclude that a field created by two oppositely charges particles would have an electric field of zero somewhere between the charges, which is observed as a horizontal (zero slope) part of the sheet at that point.
* Set up a field of two similarly charged balls and have students examine the sheet and compare it to the previous arrangements. Students may observe that the sheet has a slope at every point in the field. This may lead the students to the conclusion that there is an electric field at all points in space around two similarly charged objects.

1. **Worksheet 5 – Electric Fields**

# From modeling curriculum – E&M Unit 1 Charge and Field available at www.modelinginstruction.org

1. **Other arrangements of charge**

* Use two wood rulers to model parallel plates. Place on of the rulers on the top of the sheet and the other ruler is held underneath. The plates are “not charged” when the rulers are at the same level. Ask the students to describe the electric field between the plates.
* Move the rulers in opposite direction to add “charge” to the plates, the ruler on the top of the sheet is pushed down, becoming the “negative” plate, and the plate under the sheet is pushed upward, becoming the “positive” side (Figure 6).
* Ask the students to describe the field between and outside the plates. They should notice that:
  1. the slope of the sheet between the plates is constant, indicating that the electric field is uniform between the plates
  2. the field looks differently near the edges of the plates than in the center of the plates.
* Use a test charge to determine the shape and the direction of the field.
* Use other charge arrangements as useful. For example, use a top of a cup to model the ring of charge. Pushing the cup up from beneath the sheet shows the electric field for the ring of charge. In the center of the ring, the sheet remains flat, its slope is zero. If a test charge is placed in the center of the ring, the charge will not move because the slope of the sheet is zero. Outside the ring appears to be similar to the point charge, and so the field will decrease as inverse-square of the distance.

**Energy of the Electric Field**

Note: The concepts needed for electric potential were completely developed in the gravitation demonstration of gravitational potential. In the gravitational potential demonstration, the potential was determined to be the ratio of the potential energy to the mass, a property of the object. In terms of the electric potential, the object’s property being examined is the charge it has. The electric potential, therefore is the potential energy per unit charge,. Just like gravitational potential is the product of the field strength and the distance from the object with mass that creates the field, the electric potential is defined as the product of the field at a distance from the charged object.

1. **Review: Lycra® Sheet Field Model for gravitational potential**

* Use the sheet to review gravitational potential concepts
* Review worksheet 1 page 1 for E&M Unit 2 with students

1. **Lycra Sheet Field Model – Electric potential of a uniform field**

* Starting with a flat sheet, set up a uniform field with parallel plates previously discussed. Students will draw potential lines and explaining their reasons.
* Discuss with students the implications of changing the potential surfaces within the field.

1. **Whiteboard page 2 of worksheet 1 – uniform fields**

# From modeling curriculum E&M Unit 2 Worksheet 1 page 1 available at

# www.modelinginstruction.org

1. **Lab: Mapping electric potential**

# From modeling curriculum E&M Unit 2 Worksheet 1 page 1 available at www.modelinginstruction.org

1. **Lycra Sheet Field Model – Electric Potential of a non-uniform field**
   * Use a ball to create the electric field in the sheet. Students will draw four or five potential lines around the point charge, creating concentric circles of equal potential around the charge.

Note: The circles should be closer together near the source of the field and gradually increase in their separation as the position increases. Discuss with students the reasons for this shape.

1. **Worksheet 2 – potential in non-uniform fields**

# From modeling curriculum E&M Unit 2 Worksheet 1 page 1 available at

# www.modelinginstruction.org

1. **Other charge distributions**

* Return to the charge distributions previously demonstrated. Discuss the relationship between the field (slope) and the potential (height) demonstrated by the blanket. Show that a charge the field and voltage are not necessarily dependent on each other.
* For example, with the ring of charge situation, the electric field is zero inside the ring because the sheet is flat in that region. However, the sheet has been displaced by the ring upward, representing the potential inside the ring is not zero, although it does have a constant value.
* In another example, four identically charged point charges are arranged at the four corners of a square. When the sheet is used to construct this arrangement of charges, the center of the square will have zero slope, indicating zero electric field. However, the center will be moved upward from the plane it is on without the charges, indicating a nonzero value for the electric potential.

**Conclusions**

The Lycra® Sheet Field Model provides a physical model for both the gravitational and electric field. Research has shown that model-centered instruction provides engaging, student-centered activities that increase student conceptual understanding. Through lecture demonstrations, probing questions, and the predict–observe–explain learning cycle, students are actively involved in the development of the Lycra® Sheet Field Model at specific points in the curriculum. The model is introduced early in the curriculum and students make predictions based on their prior beliefs about gravity before the demonstration in performed. Predicting outcomes enable students to vocalize their beliefs and misconceptions, admit that their beliefs may be inconsistent with the observed phenomenon, leading to a need for a new or modified model, which will conclude with a change in their understanding. The model is progressively broken and modified to include new understandings of the gravitational field, including universal gravitation, gravitational potential energy, and gravitational potential. Students can use the lessons learned through the demonstrations as a working model that they can apply to conceptually solve problems.

Following the full development of the Lycra® Sheet Field Model to explain gravitational concepts, the model is then extended to provide an analogous model for the electric field. Since the model is fully deployed when learning about gravitation, a topic students are familiar with and whose concepts can be contrasted by experience, the application of the model during lessons on electric fields becomes a spiraled lesson instead of new content. Even advanced topics, like Gauss’ Law, could be introduced as a conceptual tool when discussing universal gravitation so that the concept becomes familiar to students and removes some of the mathematical sophistication that is inherent when learning about electric potential and charge distribution.

Further research is needed to determine student reception of the model and performance when applying the model in solving problems. However, since the model is designed on research-based principles of modeling-centered instruction and lecture demonstrations, it has the potential to provide a concrete, working model for students to use when learning about the abstract concepts of fields. The students’ role in unpacking the components of the model is most essential to its usefulness as such. When the students are engaged in discovering the model, they will see its usefulness may be more inclined to apply it, even when not required to do so.

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**Biography**

Justin Snook was born in Sabetha, KS. He received his B.A. in physics from The State University of New York at Buffalo in 2005 and completed his Master's degree (M.S.Ed. physics) in 2013 at SUNY Buffalo State College. He has taught introductory physics at the secondary level in Raleigh, North Carolina and Buffalo, New York since 2006. Justin can be reached at jstnsnook@gmail.com.

**Appendix A: Modeling Instruction**

Two important characteristics of modeling-centered instruction focuses on the ways students learn physics and the common student misconceptions, or beliefs, and students are actively performing investigations to build conceptual understanding and models with the focus of describing how objects, or systems, interact. Models provide concrete proof students need in order to change their “intuitive rules or notions” that are “rooted in everyday experience” about physics concepts (Arons, 1997). The Lycra® Sheet Field Model described in this paper provides the visual, concrete proof for students to: 1) change their preconceptions about gravity and 2) understand the nature of the gravitational and electric fields that cause the interactions between objects.

Models also provide the foundation that leads to deeper understandings of scientific concepts, the practice and nature of scientific reasoning, and the ability to problem solve and explain scientific phenomena (Khan, 2011). According to Karplus (1969), there are four basic kinds of models that scientists use to explain phenomenon[[3]](#footnote-3). Students need to recognize the usefulness of the model (when it can be applied and when it cannot, where the model fails, and when a new model is needed) before they will be willing to apply it spontaneously. Modeling–centered instruction provides students opportunities to create a model to replicate complicated, abstract phenomenon they traditionally struggle in understanding the concepts. Also, models assist students in “describing, predicting, and accounting for unobservable phenomena” and “support students in asking new questions about the world” (Starr & Krajcik, 2013).

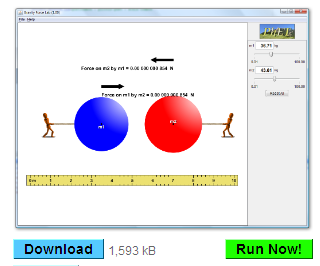
Formal model–centered instruction in physics is based on the Learning Cycle that Robert Karplus developed (Wells, Hestenes, & Swackhamer, 1995). Christina Schwartz, Reiser, Davis, Kenyon, Archer, Fortus, Y. Schwartz, Hug and Krajcik (2009) studied student use of models. During the investigation, it was observed that student are resistant to use the model(s) they have developed, indicating that they often do not see the importance of using models in their learning or in solving problems. Students need to practice applying model(s) to situations so they can become familiar with it. Once they have had many opportunities to apply a model, students should confront situations that require them to extend the model for a deeper understanding of the concept. One way in which to do this is to briefly introduce a model without discussing all of the applications or the more in depth components. When an opportunity arises to spiral back to using the model, new aspects should be introduced to the students. This can be repeated as often as needed until the model has been fully established. This agrees with Boltzer and Reiner’s (2005) claim that “a gradual progress from concrete representation into microscopic and formal representations might elaborate students’ visualization strategies”.

**Appendix B: Lecture Demonstrations**

Lecture demonstrations are a second research-based alternative approach to teaching physics. The demonstrations follow a learning cycle of predict-observe-explain to teach physics concepts. Each student must make a prediction about the outcome of the demonstration before watching the demonstration. This prediction practice attempts to actively engage the student in the learning process. In addition, students are required to share and discuss their predictions with other members of the class. After they observe the demonstrations, students compare the results with their predictions and attempt to explain what they observed. The Mazur Group at Harvard University researched the use of demonstrations in the classroom. The researchers concluded that when students make predictions in advance of the demonstration, they are made to vocalize their beliefs and are forced to recognize their inconsistency with the observed phenomenon which ultimately leads to a conceptual change. “Conceptual learning depends on students accurately observing the outcome of the demonstrations, regardless of whether their initial prediction is correct or incorrect” (Miller, Lasry, Chu & Mazur, 2013). The task of making the prediction is the important part that most teachers do not practice. Traditionally, teachers use a show and tell approach to demonstrations, like performing a magic show for the students. While entertaining the students, these kinds of demonstrations do not engage the student into learning the concepts. Also important to student understanding of the demonstration is that they need to have some knowledge of the underlying concept prior to the demonstration.

**Appendix C: Modeling Universal Gravitation Activity**

Modeling Universal Gravitation Activity

Go to <http://phet.colorado.edu/en/simulation/gravity-force-lab>

And select RUN

**Qualitative Observations**

1. How does the separation of the masses affect the force between them?
2. What happens to the force between the objects when mass 1 is doubled?
3. What happens to the force between the objects if you Cut Mass 2 in half?
4. In any of the situations did the forces ever differ in magnitude? What model(s) apply?
5. In any of the situations did the forces ever not point in opposing directions? What model(s) apply?

**Quantitative**

It is now time to build a model.

1. What THREE things can we change/vary?
2. Select an independent and dependent variable and constant
   1. DV \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
   2. IV \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
   3. C \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. Collect 10 data points, graph and linearize.

1. Select a new independent and dependent variable and constant
   1. DV \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
   2. IV \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
   3. C \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. Collect 10 data points, graph and linearize.
3. Repeat the varying mass vs. force experiment, changing the second mass.

**Questions**

1. How did varying the second mass affect your results?
2. What is the relationship between Mass and force?
3. What is the relationship between distance and the force of gravity?
4. Write out the proportions between Mass 1 (**m1**), Mass 2 (**m2**) distance (**r**) to the Force of gravity (**Fg**).

**Check with your instructor to make sure your proportionality is correct.**

1. Does your lab data for **m1**, **m2**, and **r** does equal **Fg**? Also work out your units, do they equal a unit of force?
2. Make a graph of Force vs. your proportionality
3. Determine the gravitational constant (**G**) that will satisfy your units

G=\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Write your full formula and check with your instructor.

**Appendix D**

Figures and Tables

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| Figure 1: Students supporting Lycra® Sheet during demonstration. |

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| Figure 2: Top view of a ball placed on sheet to create a gravitational field in the sheet. |

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| Figure 3: Bottom view of a ball placed on sheet to create a gravitational field in the sheet. |

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| Figure 4: Small test mass is placed on the sheet to test indicate the direction of the gravitational force from the ball |

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| Figure 5: Sheet with student-drawn gravitational field lines. |

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| Figure 6: Two charged parallel plates modeled by 50 cm rulers |

|  |  |  |
| --- | --- | --- |
| Table 1  Comparison of the types of models described by Robert Karplus | | |
| Model | Explanation | Example |
| Working | Simplified or idealized mental images for physical systems. | A sphere model for the earth where topographical features are neglected or a particle model for the solar system. |
| Analogy | Uses a comparative system to explain the workings of a new or unknown system.  Students visualize unknown phenomena in a more familiar context. | Flow of water through pipes compared to the “electric fluid” flow of charges through wires. |
| Physical | Uses a physical object to represent a system.  Students can physically manipulate the model to see relationships. | Computer simulations  Long springs for wave phenomenon |
| Mathematical | Use mathematical relationships of variables in either graphical, algebraic, or geometric forms.  Students use arithmetic reasoning to describe interactions and changes in the systems | Position vs. time graphs  Energy bar charts  Mass-velocity bar graphs  equations |
| Table 1 | | |

1. See Appendix A for a discussion of model-centered instruction [↑](#footnote-ref-1)
2. See Appendix B for a discussion of lecture demonstrations [↑](#footnote-ref-2)
3. See Table 1 [↑](#footnote-ref-3)