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Reflections

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Thoughtful Curricula Developing Thinking Students

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The Most Important Math for Learning Physical Science

Part III – Understanding Formulas

by Bob Stair

(The first two articles in this series addressed the use of histograms to analyze students' experimental data and how proportions are used to determine simple formulas. Both of these articles dealt with skills and strategies that are utilized in Introductory Physical Science (IPS) *and can be used directly with all introductory physical science students. This final article is a bit different. While you may choose to introduce your most capable students to the procedures included here, this article goes beyond what most beginning physical science students must know to be successful in a course like* IPS. *It is intended to extend teacher knowledge beyond what is necessary for students at this level. Consequently, although* IPS *purposely presents formulas in words rather than symbols, symbols are used here to extend what is in the textbook.)*

The search for relations among experimental quantities is very often a search for proportionalities. In an introductory physical science course, this search usually takes the form of collecting and graphing data, looking for a straight-line relation that passes through the origin of the graph. (Refer to the second article in this series.) There are a few times in *IPS*, however, when the initial graph of collected data does not yield the sought-after straight line. For example, suppose that a mass is attached to a string. The string is then wrapped around the hub of a rim-weighted wheel so that as the mass falls, it turns the wheel (similar to *IPS* Experiment 13.5). When the gravitational potential energy lost by the falling mass is graphed as a function of the resulting speed of the wheel's rim, the graph is a curve rather than a straight line. Curves also result if the densities of equal-mass samples of various substances are plotted as a function of the volumes of the samples, or if magnetic force is graphed as a function of the separation of two magnets (*IPS* Experiment 14.4).

How do we determine which quantities are proportional if the initial graph is not a straight line? Data graphs can take many shapes, and identifying the various relations can be tedious, often requiring curve-fitting routines that are beyond both the knowledge and abilities of most physical science students. But, with apologies to our math colleagues for leaving out some of the more esoteric relations, there are just four basic graph forms that might be of interest in an introductory physical science course. These forms are shown in Figure 1.

One of the forms—proportionality—has already been discussed in detail in a previ-

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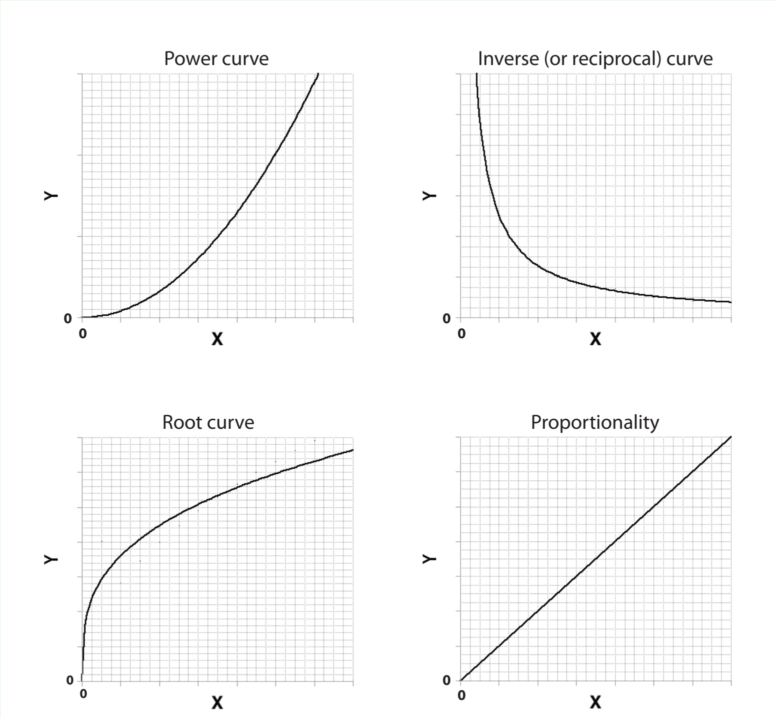

Figure 1
Types of basic curves encountered in an introductory physical science course. The names given here may be different than those found in some math textbooks.

ous article. It is the form that we strive for when trying to determine a formula that relates experimental quantities. What must be done to determine the relation between the quantities in the "non-proportionality" graphs? Since we always seek to determine a proportionality, this question becomes "*What must we do so that we can re-graph*

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Next Generation Science Standards (*NGSS*) Review Webinar

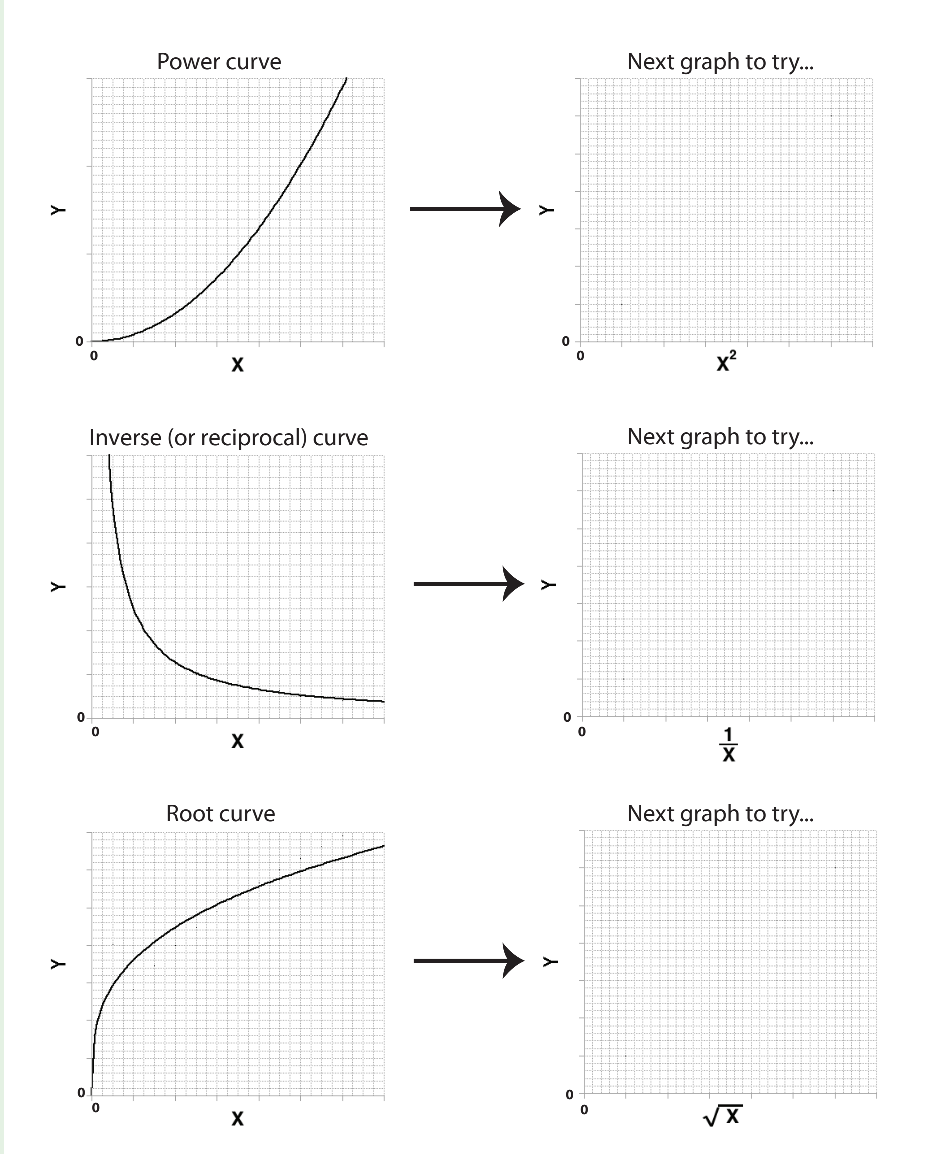
The Denver Museum of Nature & Science will host a webinar presented by our own Harold Pratt—former NSTA past president, member of the NRC staff that developed the original *National Science Education Standards*, current consultant to NSTA for the review of the NGSS, coauthor of *IPS*, and President of Science Curriculum Inc.

How to Engage Science Educators in the Public Review of Next Generation Science Standards
Presenter: Harold Pratt Date: Wednesday, May 2nd
Time: 4:30pm-5:30pm MDT Cost: Free

Register and login at: http://tinyurl.com/dmnsframework
(Note: Log in early and give yourself enough time to fill out the online registration form. Your contact information is solely for this webinar and will not be given out for marketing purposes)
Phone in for audio: Audio will be via a conference bridge phone number that will appear on your computer screen when you are logged in.

Full Description: The *Next Generation Science Standards* (*NGSS*) are now in development by Achieve. The public will have a chance to view and comment on two public drafts, with the first expected within a couple of weeks. What should educators consider when reading and reviewing a draft standards document? What are the best materials to read ahead of time to prepare for this task? How might you connect with and organize groups of educators to encourage thoughtful and informative discussions about the draft? Join us in this informal session as we explore these questions and more about the role of educators in the NGSS public review process and how science teachers can get involved.
The webinar will present a brief background on the development of the NGSS by Achieve base on the Framework for K-12 Science Education developed by the National Research Council and provide specific suggestion on how to utilize resources from NSTA to prepare for your personal review or how to facilitate a group review.

Figure 2
If a data graph shows a "non-proportional" curve, the next data analysis step depends on the type of curve. In each case, the goal is to end up with a proportionality graph—that is, a straight line through the origin— although at times it may take multiple steps to achieve this goal. If a graph shows a power curve, the next step is to plot the dependent variable (shown here as Y) as a function of the independent variable (X) squared. If the graph is an inverse curve, the next step is to plot Y as a function of 1/X. And if the graph is a root curve, the next step is to graph Y as a function of the square root of X.



the data in a form that yields a straight line through the origin?" The appropriate next steps are shown in Figure 2.

Let's look at an example. Figure 3 (on the next page) is a reprint of Figure 13.10 from the *IPS* textbook (9th edition). It shows the kinetic energy of the rim of an *IPS* energy wheel as a function of the speed of the rim. Obviously, there is not a direct proportionality between these two quantities.

See UNDERSTANDING FORMULAS on page 4

The Deadline for the 2012 *IPS* National Workshops is Approaching!

In July of 2012, Science Curriculum Inc. will offer three different *IPS* workshops on the Colorado School of Mines campus in Golden, CO. The workshops will cover Chapters 1-6, 7-11, and 12-16, respectively, of the 9th Edition of *IPS*. The dates for the workshops are as follows:

***Introductory Physical Science* – Part 1** (covering Chapters 1–6) July 15–20, 2012
***Introductory Physical Science* – Part 2** (covering Chapters 7–11) July 22–27, 2012
***Introductory Physical Science* – Part 3** (covering Chapters 12–16) July 22–27, 2012

A workshop registration form is included at the end of this newsletter, or you can download a pdf version by going to **http://www.sci-ips.com/e_workshops.htm** . For questions or additional information, please contact us, either toll-free (888-501-0957) or by email (tom@sci-ips.com).

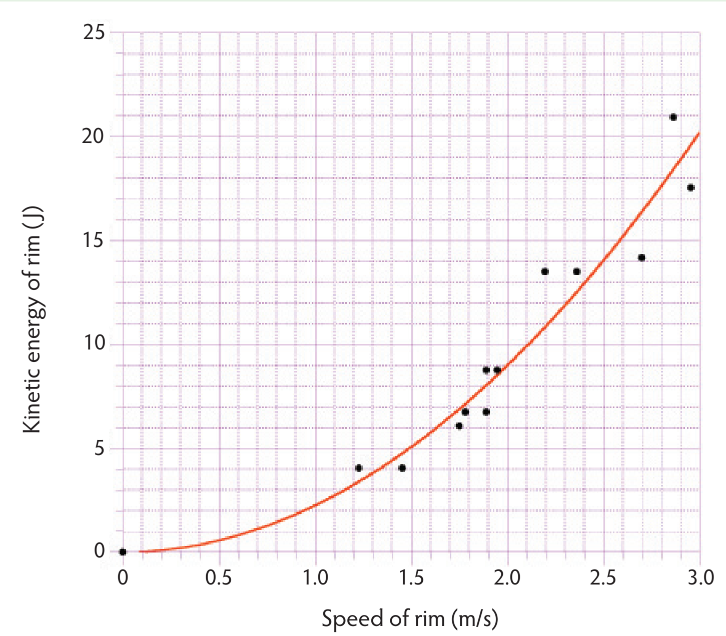


Figure 3
A reprint of Figure 13.10 from *Introductory Physical Science* (9th edition).

Initial Speed of rim (m/s)	Initial Speed Squared (m^2/s^2)	Kinetic Energy of rim (J)
1.23	1.51	4.1
1.45	2.10	4.1
1.75	3.06	6.1
1.78	3.17	6.8
1.89	3.57	8.8
1.89	3.57	6.8
1.95	3.80	8.8
2.20	4.84	13.5
2.36	5.57	13.5
2.70	7.29	14.2
2.86	8.18	20.9
2.96	8.76	17.6

Table 1
Results of the energy wheel experiment. The kinetic energy was determined from the increase in thermal energy of an aluminum cylinder used to stop the wheel.

Since Figure 3 is a "power" curve, the next step is to graph the kinetic energy (*KE*) of the rim as a function of a higher power (square) of its speed. Table 1 provides the original speed data, along with the square of the speed. Figure 4 then shows the modified graph.

The graph in Figure 4 is a straight line through the origin, so the quantity on the vertical axis (*KE*) is proportional to the quantity on the horizontal axis (v^2). This is the reason why v^2 appears in the formula for kinetic energy ($KE = ½ mv^2$)!

Another example…Figure 5 (on page 5) shows a graph of the density of equal-mass samples of various materials as a function of their volumes.

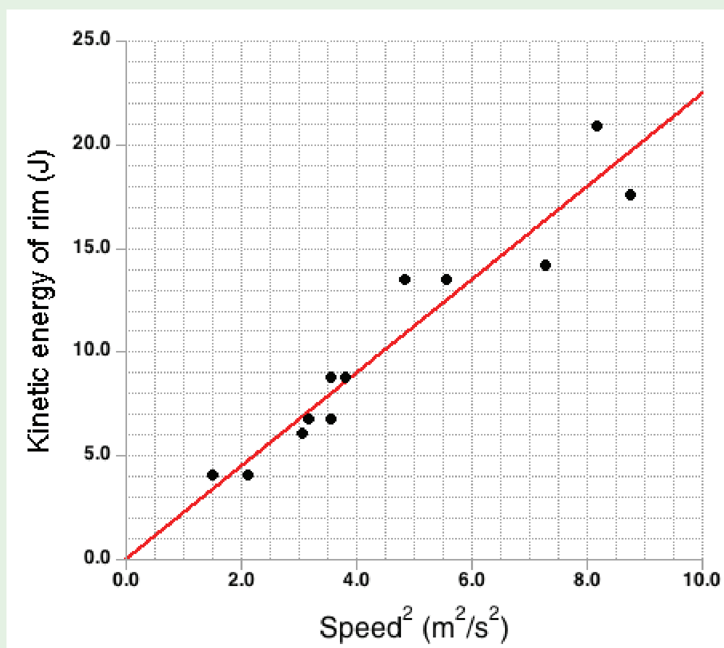


Figure 4
A graph of the kinetic energy of a weighted wheel as a function of the square of its rim speed.

See UNDERSTANDING FORMULAS on page 5

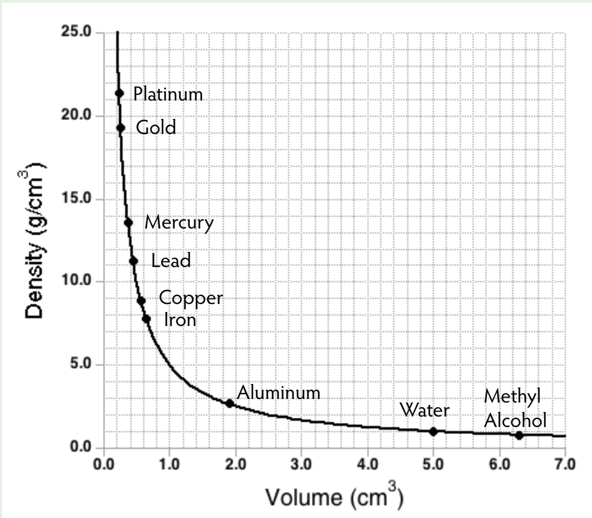


Figure 5
The densities and volumes of equal-mass (5-g) samples of various substances.

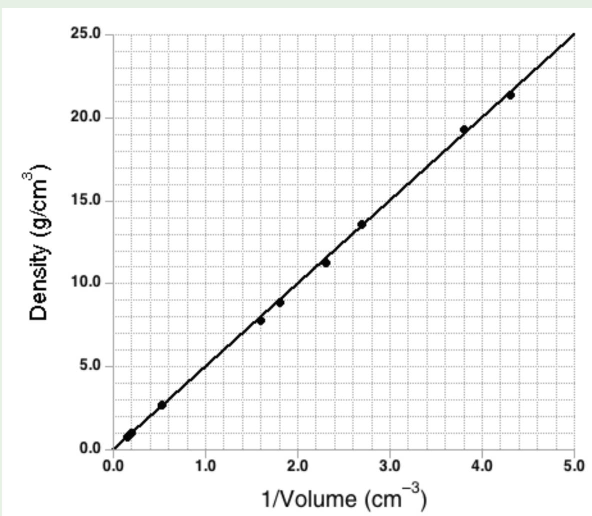


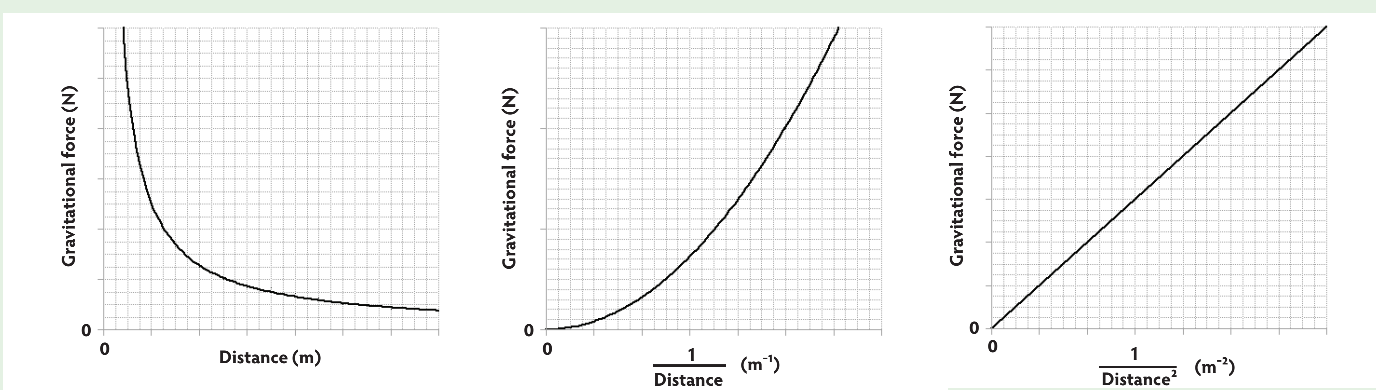
Figure 6
The data presented in Figure 5 re-plotted using the reciprocals of the volumes.

As depicted in Figure 1, the graph in Figure 5 shows an "inverse" or "reciprocal" curve, so the next step is to graph the data again using the reciprocal of the volume ($1/V$) on the horizontal axis. The resulting graph is shown in Figure 6. Apparently, for equal-mass samples, density (D) is proportional to the reciprocal of volume. This is why volume (V) appears in the denominator of the formula for density ($D = m/V$)!

One more example, this time from Newtonian physics…the dependence of the gravitational force on the center-to-center distance between two masses. The shape of a typical graph of the gravitational force as a function of separation distance is shown in Figure 7(a). It is an "inverse" or "reciprocal" graph.

When the graph is re-plotted using the reciprocal of the separation distance, Figure 7(b), a "power" curve results. The next step, therefore, is to plot the gravitational force as a function of a higher power of the reciprocal of the distance, as shown in Figure 7(c). As can be seen from the resulting straight line through the origin in this illustration, the gravitational force (F_g) is proportional to the inverse square of the separation distance ($1/d^2$). This is why the square of the separation distance appears in the denominator of Newton's Law of Gravitation ($F_g = Gm_1m_2/d^2$).

In summary, most graphs plotted in an introductory physical science will display one of a limited number of curve types. By recognizing these few basic forms, it is possible to use simple procedures to re-graph the data with the goal of obtaining a straight line through the origin. In this way, we can determine relations among experimental variables and develop a deeper understanding of the origins of the formulas we use to describe nature.



(a) (b) (c)

Figure 7
Steps to finding the proportion between gravitational force and the inverse square of the distance between two masses.

Registration for the Science Curriculum Inc.

Introductory Physical Science (IPS) National Workshops

Colorado School of Mines

July, 2012

Course selection - please check the appropriate workshop(s):

___ ***IPS* Part 1 – Properties of Matter** **July 15–20, 2012**
___ ***IPS* Part 2 – Atoms and Molecules** **July 22–27, 2012**
___ ***IPS* Part 3 – Energy and Forces** **July 22–27, 2012**

Tuition cost: The tuition cost is $300 for each one-week workshop.

For maximum benefit, it is highly recommended that the **IPS Part 1** *workshop be taken prior to the* **Part 2** *and/or* **Part 3** *workshop.*

NOTE: Since **IPS Parts 2** *and* **3** *meet concurrently, it is not possible to enroll in both.*

NAME ____

GENDER *(for lodging purposes only-please circle one)* M F E-MAIL______________________

HOME ADDRESS ______________________________________

HOME PHONE ______________________

SCHOOL NAME ______________________ PHONE ______________________

SCHOOL ADDRESS ____________________________________

SCHOOL DISTRICT NAME ______________________________

In what area of science teaching do you teach the most classes? (please check one)

Physical Science ____ General Science ____ Earth Science ____ Other (please specify) ____________

What was your major in college? ______________ Graduate concentration, if any ______________

Have you attended a previous *IPS* or *Force, Motion, & Energy* (*FM&E*) workshop or summer program? Yes No

Have you previously taught *IPS* or *FM&E*? Yes No

If yes, which program and for how many years? ____________ At what grade level(s)? __________

Credit: Credit is awarded by Colorado School of Mines as graduate-level semester hours in continuing education. Each one-week workshop can be taken for 2 semester hours credit.

I do ___ do not ___ plan to take the workshop for credit.

NOTE: The tuition amount is the same with or without credit, and all registrants are expected to complete and submit all assignments.

LODGING AND MEALS *(Please complete this section <u>even if you will not be staying on campus</u>.)*

Lodging preference: ***(All accommodations are single bedroom in 2-4 bedroom suites.)*****

___ I will be staying off-campus and will not need on-campus accommodations.

___ One week: $250.33 (6 nights: check-in Sunday; check out Saturday)

___ Two weeks: $531.54 (13 nights (includes weekend between workshops): check-in Sunday; check out Saturday)

Meals:* ***(It is recommended that participants have lunch together to facilitate the informal exchange of ideas.)***
<u>Commuters – please complete the lunch line even if arranging for your own lunch.</u>

Breakfast (Monday-Friday) ____One week ($38.47) ____Two weeks ($76.94) ____I will arrange for my own breakfast.

Lunch (Monday-Friday) ____One week ($48.42) ____Two weeks ($96.84) ____I will arrange for my own lunch.**

Dinner (Monday-**Thursday**) ____One week ($42.40) ____Two weeks ($84.80) ____I will arrange for my own dinner.

* The prices quoted for lodging and meals already include 7.6% lodging and meals tax.
** Please be aware that workshop participants who bring their own lunch are not admitted to the dining hall.

PARKING

Like many universities, Colorado School of Mines now charges for parking anywhere on campus, including streets. Whethe you will be commuting or staying on campus, if you bring a vehicle with you, you will need a parking permit. Please selec one of the following:

___ I will <u>not</u> have a vehicle on campus and will not need a parking permit.

___ I'll be commuting or staying on campus and will need a parking permit for <u>one</u> Monday–Friday workshop. ($20)

___ I'll be commuting and will need a parking permit for <u>two</u> Monday–Friday workshops. ($40)

___ I will be staying on campus for two weeks. I need a parking permit for two weeks, including the intervening week-end. ($48)

DEPOSIT AND FINAL PAYMENT

A non-refundable deposit of $100 (payable to Science Curriculum Inc.) must accompany this application.

Please mail both to:

Coordinator of School Services
Science Curriculum Inc.
200 Union Blvd, Suite G-18
Lakewood, CO 80228

A confirmation of your registration and deposit will be sent to you, along with an invoice for the remaining balance.

Due to planning and commitment deadlines at Colorado School of Mines, *all outstanding balances will be due and must be paid in full* ***by June 8, 2012***.

Signature ____ **Date** ____________________

If you have any questions, please contact us at 303-988-5041 (toll-free 888-501-0957) or email workshops@sci-ips.com .