Linear Systems: An Interactive Unit

Honors Thesis

by

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Advisor:

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Abstract:

In teaching mathematics, it is crucial to present new material in such a way that will be meaningful for the students, allows them to construct their own understanding of the concepts, accomplishes state standards, and meets the needs of various types of learners. This unit of lesson plans was constructed with these principles in mind, with varying types of activities to appeal to differing styles of learning, and real-world connections designed to make the activities and concepts relevant to students’ lives.

Acknowledgements:

- I want to thank Dr. Beverly Hartter for advising me during the development and construction of this project. I am incredibly grateful for her assistance all through this project, as well as her guidance throughout my career as a per-service educator.
Objectives: In this unit, I want my students to learn how to solve systems of equations, and know how to set up a system of equations given information in a real-world setting. I also want my students to be able to analyze their solutions in order to determine what the solution means – is there no solution, one solution, or an infinite number of solutions. Does the solution make sense? I also want my students to be able to operate within the coordinate space – be able to find points, graph planes, etc.


Assessment: Unit assessment is the final project, described in the unit plan. Minor assessments are given throughout each lesson, and I intend to assign homework nearly everyday. Students will be allowed to ask questions (2-3 problems) about the homework the very next day at the start of the class, and the assignment will be picked up the following day. Therefore, students will actually have two days to complete assignments, so if they are busy one night, they can complete it the next night (although they will not have a second chance to ask questions about the assignment.) I will most likely pick a variety of problems from the textbook for the students to work on for homework. I plan to choose a few problems that are answered in the back of the book so that students can assess themselves to determine if they are correctly solving the problems.

Rationale:

**Graphing Linear Systems:**
Since students should be able to graph a line correctly, I wish not to focus on this aspect of the lesson because the focal point is the intersection of the lines, not graphing the lines themselves. By using graphing software to expedite the graphing process, the students’ attention is directed at analyzing the graphed equations. This is also more practical for having the students check their own work, since graphing is time-consuming. Graphing calculators are very useful here, but other graphing programs will work just as well. These programs are easy to use after minimal training, and students are able to quickly graph lines, as well as give the point of intersection.

**Solving Systems Algebraically:**
In this lesson, students are beginning to develop methods for solving systems without having to graph them (which is time consuming and inaccurate without technology). After they are familiar with both methods, the students should be able to see certain aspects of a system that makes one method preferred over the other, although solving the system with a method they are most comfortable with is sufficient. By stating the properties that allow us to manipulate the equations, the students are able to see how and why we are able to manipulate them a particular way. This way, the students are not just memorizing steps in a process, but are seeing how the process is developed. This will help them develop the necessary skills and ideas needed to solve matrices.

**Solving Systems of Inequalities**
Solving inequalities should be a review from algebra, so being able to solve them to obtain an inequality they can graph is vital. Again, since inequalities should be review, technology is very useful in accelerating the graphing process, and allows the students to not get held up graphing systems. Graphing software can be deceiving, though, so it is crucial that the solutions do in fact make sense in the context of the problem.
**Linear Programming**
This lesson focuses on applying what the students now know about systems to real-world situations. Not only does this section help students develop a deeper understanding of how to solve systems, it also helps them analyze solutions and information from the graph, as well as evaluate information given in the problem.

**3-d Graphing:**
This section is crucial to not only introduce three-dimensional coordinates, but to give meaning to solutions of systems with three variables. The class activity helps kinesthetic learners by allowing them to get up and physically show the location of a point in the coordinate space.

**Solving Systems of Three Variables:**
The students will use their knowledge of solving systems of two variables and apply it to solving systems of three variables. The opening activity is a creative way to not only engage students with the material, but to try to have students draw connections between solving systems with two variables. This lesson also helps build the skills and ideas needed to solve matrices.
Solving Systems Algebraically- solving by substitution; elimination

Concepts: Solving systems of equations by substitution or elimination.

Indiana Academic Standards:
A2.2.2 Use substitution, elimination, and matrices to solve systems of two or three linear equations in two or three variables.

Objectives: Students will solve systems of two equations in two variables by substitution.
Students will solve systems of two equations in two variables by elimination.
Students will analyze their solutions once found.

Vocabulary: Equivalent systems

Lesson Outline:

Introduction: Give the students a system that is not easily solved graphically due to the solution involving a fraction, and ask them to solve it graphically – without technology. Example: \{ 3x + 5y= 7, 4x-2y=13; y= -11/26, x=79/26. They should notice that the solution is hard to determine. There must be a better way to solve systems of equations!

Development of the Concept:
1. Example on board: \{y 2; y = 3-x. Let’s hear any ideas that you may have about how to solve this problem, class. Write ideas on the board. If student suggests substituting the first equation in for y in the second, commend their good observation. If not: Since these are the equations of lines, what does y=2 look like? (horizontal) What does y=3-x look like? Where do they intersect? How can we find the point of intersection just from the equations, knowing that y=2 is a horizontal line? Once the students realize the substitution method for this example, provide a slightly more difficult example: \{y=3x; 2y + x = 5. Have the students use the last problem as a parallel to solve this problem - by substituting 3x for y in the second equation, then solving. This method of solving linear systems is called substitution. Now let’s work through another example. \{2x -2y= 5; x +2y=1. y= -Y2. To solve this system, it required a lot of work, and as mathematicians, we like to find the quickest way to do things – so is there a better way?

2. Before we can find a more efficient way to solve this system, we need to think about algebraic properties. If we add a number to both sides of an equation, the equation stays true – what property allows us to do this? (addition property). Same thing applies to subtraction – subtraction property. If we multiply/ divide both sides of an equation by a number, the equation still remains true, by what properties? (multiplication, division properties) Since an equation equates two different expressions (such as x +2y=1 in the last problem), we know that both sides are equal. A property lets us replace either side of an equation in for the other side – who remembers this property (we just used it to solve the previous systems)? Substitution property. So, let’s use these properties to try to find a better method for solving systems of equations.

3. Let’s use the previous example, since it seemed so lengthy to solve using substitution \{2x -2y= 5; x +2y=1. Using the addition property, we know that we can add a constant to both sides of an equation, so let’s add 5 to both sides of equation two. Why do you think I just did that, (student)? I did that to the substitution property – we know that 2x -2y= 5, so we will replace a 5 with 2x -2y, which yields x +2y + (2x-2y)=1+5. Simplify this please, (student)\rightarrow 3x+0y=6. Now, who knows what to do next? So
integer equal to itself, then changing how the integer looks (finding a sum/difference that still equals the integer, using multiplicative inverses). This way, the students can see that the expressions are still equal to the starting integer, and can hopefully use this to draw parallels to expressions with variables.

**Gearing Up:** If the students seem to know and easily use the concepts, I will have them analyze the solutions to inconsistent/dependent systems, without telling them that they are inconsistent/dependent. I will also have them create a list for the “flags” that help differentiate between which method is most time efficient instead of having them tediously work through numerous problems.
Systems of Inequalities

Concepts: Solving systems of inequalities

Indiana Academic Standards:
- A2.1.6 Solve an inequality by examining the graph.
- A2.2.3 Use systems of linear equations and inequalities to solve word problems.

Objectives:
- Students will solve inequalities.
- Students will graph inequalities.
- Students will find and write the solutions to systems of inequalities.

Materials: Graphing software

Lesson Outline:

Introduction: Now that we know how to solve systems of equations, we can now look at systems that contain inequalities instead of equal signs, but first, let’s review inequalities.

Development of the Concept:
1. How do we solve an inequality? Are there any special situations that we need to watch for? Review how to solve inequalities – just like solving equations but need to watch out for sign changes because this changes the direction of the inequality. When do we use a broken line, and when do we need a solid line when graphing inequalities? Review how to graph inequalities, so that the students recall that a less than / greater than contains a broken line since the points on the line do not satisfy the inequality, and that less / greater than or equal to equations contain a solid line since the points on the line do satisfy the inequality. Now we have the line graphed, but do other points satisfy the inequality? Also, stress the importance of filling in all points that satisfy the expression – so one half of the graph, separated by the line.
2. Give the students a system of inequalities, and ask them to solve by graphing. Have a student graph their solution on the board, and have the class discuss their solution. What is the solution to this system? Why is it more than one point? Discuss how to analyze the solution to write an expression for the solution to an inequality.
3. Show the students how to use graphing software to graph a system of inequalities, then have them solve several systems of inequalities using the software.

Closure: Have each student create two systems of inequalities that do not have a solution, to be handed in.

Gearing Down: If the students are having difficulty solving inequalities, I will show them how to replace the inequality sign with an equal sign, then solve the equation. Finally find a point that solves the equation, and see if the point makes a true or false statement in the inequality, and give it the appropriate sign.

Gearing Up: If the students easily grasp the concepts, I will have the students try to develop a method for solving inequalities without graphing (using elimination and substitution).
Linear Programming

Concepts: Finding max/min values; writing linear programs

Indiana Academic Standards:
A2.2.3 Use systems of linear equations and inequalities to solve word problems.

Objectives: Students will graph linear programs.
Students will find possible solutions to a linear program.
Students will analyze information from the graph to discern solutions to a linear program.

Vocabulary: linear programming, objective function, constraints, feasible region

Materials: Worksheet that contains the Warm-up activity

Lesson Outline:

Warm-Up: Give the students the following problem to solve: You want to make a fruit basket of apples and pears for your Aunt Betty. The basket must have at least 2 apples and 2 pears, and have at least 12 pieces of fruit. If apples cost $.25 apiece, and pears cost $.50 apiece, and you have $5 to spend, what fruit can you afford to have in the fruit basket? Let the students work in small groups if they wish, and give them about five minutes to work on the problem, encouraging them to try various methods. Since the problem does involve inequalities, they will probably wish to graph the problem. What were the possible combinations of fruit that you could buy for the basket? How did you find these combinations? What is the most fruit that you can buy?

Introduction: We solved this problem using a technique known as linear programming – a technique that identifies the max/ min value of some quantity. The quantity, in this case fruit, was modeled using an objective function. We had a minimum number of each kind of fruit, a minimum total of fruit, as well as a limit on how much we could spend – these limiters are called constraints. When we graphed each constraint, all inequalities, we saw that all the constraints had an area in common. This area is called the feasible region – the solution to the problem will be located in this area. Who noticed something in particular about the location of the point of the maximum number of fruit? Where are the points that contain the minimum number of fruit, keeping all the constraints in mind? What is special about these points?

Development of the Concept:

1. If a student did not notice, show them that the maximum or minimum of the problem was found on the vertices of the feasible region. A maximum or a minimum is always located on a vertex of the feasible region. Give the students another system to solve using linear programming, and have them locate the vertices, then the minimum / maximum values.
2. Give the students the following example and have them solve it. Jim wants to start a car dealership that sells Moto-Hatch vehicles, and is able to finance any number of vehicles less than five. He can fit a maximum of six sedans or ten coupes on his lot. To become a Moto-Hatch dealer, the company requires that the lot have at least two sedans and three coupes. What are the possible combinations of vehicles that Jim can afford to have on his car lot? Solution – {x+y<5, x>=2, y>=3. No value satisfies this program, although there appears to be an intersection at (2,3), this is not true since the line y=-x+5 is dashed and does not satisfy the inequality. So Jim is unable to be a Moto-Hatch dealer.
Maybe he should start out selling used cars. This is why it is important to analyze the information and graph correctly in order to obtain true solutions.

**Closure:** Have each student create their own problem that needs linear programming to solve it, and solve it themselves, then trade with a classmate, and solve each others problem. Collect at the end of class for an assessment.

**Gearing Down:** If the students are having difficulty with the concepts, continually break the problems into steps: find the constraints, graph the constraints, find maxima/minima points, then interpret the results.

**Gearing Up:** If the students understand the concepts easily, give them situations with more constraints.
Graphs in Three Dimensions

Concepts: Graphing points and lines in three dimensions

Indiana Academic Standards:

A2.1.4 Graph relations and functions with and without graphing technology.

Objectives: Students will be able to graph points in three dimensions.

Students will able to graph lines in three dimensions.

Students will be able to graph planes using traces.

Vocabulary: coordinate space, ordered triples, trace

Materials: Big unit cube, stack of unit flats

Lesson Outline:

Introduction: On the coordinate plane, we only need two pieces of information to find an exact location, but what about in the real world? Think about a skyscraper with identical floor plans. (Use unit cube or a stack of unit flats--each unit is a room, dividing lines are hallways) If we think about finding a room in the building, what information do we need to know?--how many hallways left, how many hallways right, what floor. Since we can only use two coordinates on the coordinate plane, the coordinate plane needs to be changed to accurately model the real world that we live in. This new structure is called the coordinate space—it exists in three dimensions, just like we do.

Development of the Concept:

1. Explain how the coordinate space is set-up—x-y plane (coordinate plane) lies flat, and a new axis, the z-axis, runs vertically through (0,0), giving us a grid in three dimensions. Think about the corner of the room—the floor is the x-y plane, and the walls are the x-z and y-z planes. What do you think the coordinates in the coordinate space will look like? (x,y,z). These are called ordered triples (as opposed to ordered pairs). Show how to plot points using three dimensions. Provide several examples of points, and ask the students to show/explain where the points are, in relation to the corner of the room.* Give the students three axis graph paper, and have them graph more points on these axes so that they understand how to graph and find the coordinates of a three-dimensional figure.

1*. One way to do this to appeal to kinesthetic learners is to start with the corner of the room as a set of axes—x, y, and positive z, and have the students locate the point when given the coordinates (all coordinates will be positive) and explain what unit you wish to use (tiles, feet, meters, desks, etc.). Then, create a set of axes (x, y, and z) in the center of the room (two yard sticks and a gift-wrap tube work well). Explain what unit you wish to use again (tiles, feet, meters, desks, etc.). If more space is needed, move the desks away from the axes. Give a ball to a student, and have them locate a point that you give them by holding the ball where they think the point is. Have the class critique their location; obviously, exactness isn’t a major priority, but does the student have the general idea of where the point is? Give each student who wishes a turn locating the point with the ball, and have another person confirm if the person is correct.

2. In the coordinate plane, lines were the graphs of linear equations. What do you think the graphs of linear equations can look like in the coordinate space? We know how to plot points in space, but what do you think y=x+1 looks like? Very similar to graphing on coordinate plane—found solely on plane dealing with the two variables—
x-z, x-y, y-z. Show a few examples – y = x + 1, z = 2x – 2, y = 3 - z. What happens when an equation contains all three variables? Is this even possible?

3. Let’s plot an example, using intercepts – relate to method of graphing using intercepts on coordinate plane. Find the x, y, and z intercepts, graph them, then connect the dots. What figure is given when we plot the points? – a leaning triangle. Can the graph extend out beyond this triangular region? Yes, and the entire graph is a plane – imagine a copy of the x-y plane oriented so that it goes through the three points. Going back to the corner of the room as the axes example, show how the ceiling is a plane, which just so happens to be parallel to the floor (x-y axis).

4. Relate to CNC machining – the machine uses coordinates to create an electronic grid of the material, and the machine moves along this “grid”, which can be thought of as the x-y plane. The depth of the cut is vertical movement, so moving in the z-direction. This requires the use of three dimensions to create precise pieces.

***Hopefully, I can arrange a visit to the shop and have the shop teacher or a qualified student show the class how this actually works. If no CNC machine is present, a mill could work, although the CNC example is ideal. This of course, depends highly on the school’s rules, availability of the needed machinery, and availability / cooperation of the technology instructor. This will help visual learners because they are actually viewing the process. To convince a skeptical technology instructor, explain that the students observing the machine in action may entice students who otherwise wouldn’t have been exposed to the equipment to take technology classes.***

Closure: How do planes intersect one another? - intersection is a line, or planes are parallel. How can three planes intersect each other? Have the students draw the possible ways three planes can intersect each other. Pick up this activity as the day’s assessment.

Gearing Down: If the students are having difficulty understanding the concepts, I will spend more time having them graph points, and giving the coordinates of points that are graphed, so that they become more familiar with the coordinate space. I will also continually draw numerous parallels to the coordinate plane, showing how the space is very similar to the plane.

Gearing Up: If the students understand the material with ease, I will have them graph several planes on one set of axes so that they can find out how difficult it is to accurately graph several planes on one set of axes – leads into solving systems of three variables.
Systems with Three Variables—solving by elimination; by substitution

Concepts: Solving systems of three equations in variables using substitution and elimination.

Indiana Academic Standards:
A2.2.2 Use substitution, elimination, and matrices to solve systems of two or three linear equations in two or three variables.

Objectives: Students will solve systems of three equations using substitution.
Students will solve systems of three equations using elimination.
Students will analyze their solutions to systems of three equations.

Materials: Handout NE7, NE 76, NE 77,

Lesson Outline:

Warm-Up: We know how to solve systems with two variables, but what about systems of three equations with three variables? What does a system of two equations with two variables mean? Give the students NE7 handout, ask them to take a few minutes to try and figure out how to solve this problem, writing down the steps they used. They can work in groups, with partners, or by themselves.

Development of the Concept:
1. Why is it difficult to solve this problem by graphing? What are some other methods that your group tried? Hopefully, some students used their knowledge of systems of two variables to try to use substitution/elimination. Besides using guess and check, if the student solved this problem, they had to use substitution or elimination—they just may not have realized it. Bring this to students’ attention when they explain their method for solving the problem.

2. Bring up the closure activity from yesterday—how three planes intersect. Have the students discuss their solutions, filling in any missed possibilities. Since three planes intersect in these ways, and the planes are solutions to one equation, the intersections are solutions to what, (student)? Intersections are solutions to the equations that the planes are solutions to—either two or three planes. Knowing this, which planar intersection do we need so that we are given a solution that satisfies the system? When is this solution unique?

3. Some of you tried to use substitution to solve the problem, so let’s see how to apply this to a system. Example: \( \begin{cases} x + y - z = 1, \\ 2x + 3y + z = 2, \\ x - 2y + z = 2; \end{cases} \text{ } x = 1, y = -1, z = -1. \) Work through this problem on the board, asking students for suggested steps using substitution. Emphasize how after the equation is substituted into the other two, a new two-equation system in two variables is formed, and the solutions are equivalent. Then all that is needed is to solve the system of two equations, which the students should know how to do—so have them do this. After finding all the unknowns, be sure to check to make sure that the solution found is true for all three equations.

4. Using substitution for a system of three variables in three unknowns is very similar to using substitution to solve a system of two equations in two unknowns. Now, let’s solve a system of three equations in three unknowns using elimination to see the similarities and differences from solving a system of two equations in two unknowns. Solve \( \begin{cases} x + y - z = -1, \\ 2x + 3y + z = -2, \\ x - 2y + z = 2; \end{cases} \text{ } x = 1, y = -1, z = -2. \) Again, have students give suggestions for steps to work through the problem. Solution should be the same as found using substitution, since same system is used.

5. Have students solve \( \begin{cases} x + y + z = 0, \\ 3x - 2y - 5z = -5, \\ 2x + 2y + 4z = -1; \end{cases} \text{ } x = 2, y = -3, \)
Using the method of their choice. Give them a few minutes to work on the problem, walk around helping students with questions. After the students have found the solution, have two students come to the board and show how they found the solution – one student who used substitution, and one who used elimination. Have them explain their processes, and have the class check their work for them.

6. Systems with no solutions: Have the students solve \( x+y-z=2, 3x-5y+2z=7, -2x-2y+2z=3 \). Ask for their solutions – shouldn’t be any! The first and third equations are parallel planes – therefore, there are no solutions to this system.

7. Systems with infinite solutions: Have students solve \( x+y+z=5, x-y-z=-5, 3x-y-z=-5 \); intersect in a line: \((0, y, 5-y)\)

Closure: Pass out the NE76, and NE77 problems, and have the students solve both problems, being sure to show their steps. They must use elimination and substitution to solve both problems (therefore they will be solving each problem twice). No work means no credit for this activity – guess and check will not be acceptable.

Gearing Down: If the students are having difficulty understanding the concepts, I will work through more examples with them, and constantly drawing parallels to solving two equation systems.

Gearing Up: If the students have a good grasp on the concepts, I will have them construct their own systems with one, no, and infinite solutions. Another activity would be to give the students the intercepts or the traces of the planes, and have them find the equation of the plane.
Final Assessment:

Project: The students will be able to pick their medium for this project: written report or Power-point project; however, they will have to present their project in some manner – presentation, visual display, etc., so that everyone can see the variety of work. The students can work in small groups (no more than three), or by themselves, but everyone must be responsible for some aspect of the project. For this project, the students have numerous options, and if they have their own idea they can ask me if they may do it. The students will either:

1. Create a fictional situation in which a system of equations has no solutions, or infinitely many- they must create both a system of two equations and a system of three equations.
2. Create a fictional situation in which a system contains at least one nonlinear equation. Examples – using parabolic / logarithmic relationships to model a situation.
3. Create a linear program of three variables, and find the solution(s).
4. Construct (physical models) all possible intersections of three planes, and give a system for at least three of the figures.
5. Any idea they may have, approved by me.

Several possible ideas: economics – a product will never meet the demand/ consumers never meet the supply or demand is identical to supply; biology- endangered or escalating populations. The equations the students chose need not be linear, although linear systems are sufficient. A major component of the project is the presentation, which is required; examples include a display, verbal presentation, or other form approved by me.

Rubric:

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<thead>
<tr>
<th>Report – 60 pts.</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
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<tbody>
<tr>
<td>Calculations – 20 pts.</td>
<td>No work shown, or work is entirely incorrect</td>
<td>Little work shown, given work is somewhat correct</td>
<td>Some work is shown, mostly correct</td>
<td>Most work is shown, mostly correct</td>
<td>All work is shown and correct</td>
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<tr>
<td>Analysis – 20 pts.</td>
<td>No analysis given, analysis incorrect</td>
<td>Analysis given, analysis incorrect</td>
<td>Analysis given, not complete</td>
<td>Analysis is mostly correct</td>
<td>Analysis is correct</td>
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<tr>
<td>Mechanics – 20 pts.</td>
<td>-2 Points for every mistake – includes punctuation, grammar, run-on sentences, incorrect tense, etc.; more than 10 mistakes = rewrite</td>
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<td>Presentation 40 pts.</td>
<td>0</td>
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<tr>
<td>Content – 20 pts.</td>
<td>Presentation contains no relevant information</td>
<td>Presentation contains little or incorrect information</td>
<td>Presentation contains some necessary, but correct, information</td>
<td>Presentation contains all necessary information for audience to comprehend</td>
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<tr>
<td>Creativity – 20 pts.</td>
<td>Presentation is shoddily constructed</td>
<td>Presentation contains minimum requirements, not well thought out</td>
<td>Presentation contains more than minimum requirements, well thought out,</td>
<td>Presentation attractive, exceeds requirements, well thought out and constructed</td>
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**Resources:**

Fruit Basket Fun

For this exercise, you may work in small groups or by yourself. Be sure to show all work, including drawings, graphs, and other methods used.

You want to make a fruit basket of apples and pears for your Aunt Betty. The basket must have at least 2 apples and 2 pears, and have at least 12 pieces of fruit. If apples cost $.25 apiece, and pears cost $.50 apiece, and you have $5 to spend, what fruit can you afford to have in the fruit basket? Show your work in the space below and on the reverse side, if needed.
Consider the apples, bananas, and oranges shown below. Given that scales a and b balance perfectly, how many apples are needed to balance scale c?
Assess the symbols below. Given that scales a and b balance perfectly, how many spades are needed to balance scale c?
Consider the celestial bodies below. Given that scales a and b balance perfectly, how many suns are needed to balance scale c?
Edmonds, Joanne H.

From: Edmonds, Joanne H.
Sent: Tuesday, July 24, 2007 10:46 AM
To: Hartter, Beverly J.
Subject: Phil Loehmer's thesis

Beverly—Thanks for your phone call. I checked our notes on Phil's thesis and found a copy of the original email sent him by Gaylena Merritt, the Honors Post-graduate Fellow who assisted with thesis review. What we need from Phil is 2 things:

He needs to submit an introductory statement to his unit of lesson plans, so that readers of his thesis will understand the rationale for his basic concept and will also have some information about his process as he created these plans. In other words, why did he chose his particular topic, and what kinds of decisions did he make along the way, while he was assembling his material.

In addition, he needs to correct a typo in the acknowledgements section: "per-service" needs to become "pre-service."

You say that you have a current email address for Phil, so perhaps you can forward this email to him. If he sends you the relevant pages as an email attachment, and if you then send the thesis over to us, I'll make sure it gets sent to Bracken.

Thanks so much—
Joanne

Joanne H. Edmonds
Associate Dean, The Honors College
Ball State University
Muncie, IN 47306
USA

7/26/2007