A Lively Loaded Room

Content Focus: Math
- Calculation: Algebraic Symbols
- Measurement: Objects And Units
- Modeling: Spatial Reasoning

Content Focus: Technology
- Construction Technologies

Content Focus: Built Environment
- Measuring/Estimating
- Stress

Performance Outcome
- Calculate the load your classroom floor is supporting and speculate: How much would be too much?

Standards/Interdisciplinary Connections

S	**S**	**L**	A	**M**	**T**
Science	**Social Studies**	**Language Arts**	Art - Visual	**Math**	**Technology**

How To Read The Symbols: The symbols in **bold** indicate the subject standards that this lesson satisfies.

Lesson Outline (1 - 3 Lessons)
1. Motivation
2. The Challenge
3. Estimate The Live Load
4. Determine A Factor Of Safety
5. Present
6. Compare The Results To Codes
7. Reflection
8. Extensions And Variations
9. Middle School Standards

Salvadori Prerequisites

- FOUNDATION - BASIC SKILLS: Measuring/Estimating (Activity #2)
- FOUNDATION - STRUCTURES 101: Stress Test

CONCEPTS

- Buildings are designed to carry **loads**: the weight of structure itself, the weight of the people, and the weight of the equipment.
- Loads are divided into categories (**dead** and **live**) to help distinguish between constant and changing loads.
- Structural engineers make conservative estimates of the loads that need to be supported when designing a building. This conservative estimate is called the **design load**.

RESOURCES

On-Line

- http://www.pbs.org/wgbh/buildingbig/lab/loads_text.html - Information on dead and live loads
- http://composite.about.com/library/weekly/aa122997.htm - Information on factors of safety
- http://www.mywiseowl.com/articles/Factor_of_safety - Another site on factor of safety

Books

- Salvadori, Mario and Michael Tempel. *Architecture and Engineering – An Illustrated Teacher's Manual on Why Buildings Stand Up*. The New York Academy of Science, 1983.
- Salvadori, Mario. *The Art of Construction*. Chicago: Chicago Review Press, Inc., 1990.

MATERIALS

Facilitator

- ➊: Q&A
- ➊: Group Rubric

Students

- ⭘: Activity Sheet: Estimating Classroom Live Load
- Two or more bathroom scales, pencils, paper, tape measures

MOTIVATION

- *How much do you think I weigh?*
- *How can we find out?*

Step on a bathroom scale.

- *Assuming that this scale is accurate, is it showing my true weight*? ⭘: Q&A
- *How could I make the reading on the scale go up right now?*

Grab a large book or some other heavy object and step back onto the scale.

- *Is there a limit to how much weight I can carry onto this scale?* ⭘: Q&A
- *How could I make the reading on the scale go down?*
- *What is the minimum reading the scale can have with me on it?* ⭘: Q&A
- *If engineers were to design a scale specifically for me and anything I can carry, what is the range of weight readings the scale should have (assuming my weight stays constant)?* ⭘: Q&A

Now let's think about buildings. How do you think engineers determine how much weight our school building should support?

- *Let's start at the bottom. What is the absolute minimum amount of load acting on our school building?* ⭘: Q&A

This load is the load of the structure itself. It is called the ***dead load****. When I stand of the scale, the dead load is the weight of my body.*

- *Why do you think it is called the dead load?* ⭘: Q&A
- *If the load of the structure is called the dead load, what do you think engineers call the weight of all the things that go inside the building that it must support, like machinery, people, and furniture?*

This is called the ***live load****. When I stand on the scale, the weight of my clothes and anything else I am carrying is the live load, because it can easily change.*

- *Now let's concentrate on our classroom. What are the forces acting as dead load on the classroom floor?* ⭘: Q&A
- *What objects in our classroom are part of the live load?* ⭘: Q&A
- *Why do you think it is important for engineers to distinguish between live loads and dead loads?* ⭘: Q&A

THE CHALLENGE

Your challenge is to think like an engineer in order to find out how much weight the floor of the classroom should be able to support without collapsing. In order to do this, you will need to estimate the actual live load of the classroom, then come up with a factor of safety to determine the ***design load*** *(the actual amount of weight the floor can hold).*

ESTIMATE THE LIVE LOAD

Since the live load is variable *(meaning it can change), our estimate will reflect the live load for* right now*.*

Distribute the activity sheet. ⭘: Activity Sheet: Estimating Classroom Live Load.

In groups, students walk around the classroom looking for items that should be included as part of the live load. Have them include only large items (about 5 lbs. or more) or items whose collective weight is over 5 lbs. (like books). As they do so, they fill out the first two columns of the chart on the activity sheet ("Items" and "Quantity"). For items such as chairs, computers, or people, students count up and enter exact amounts. For objects like books, students estimate the amounts.

After a few minutes, students return to their seats. With their help, compile a list of items on the board to ensure that all students include the major items.

- *How are we going to find the weight of all these items?*

Remember that we are estimating the live load – calculating the actual load, down to the nearest pound, would be extremely time-consuming.

- *How should we estimate the weight of all the people?* ⭘: Q&A
- *How should we estimate the weight of all the desks and other furniture?* ⭘: Q&A
- *How should we estimate the weight of all the books?* ⭘: Q&A

In groups, students weigh and estimate to complete the third column on the activity-sheets. When they have done so, they add all of the figures together to get a total live load estimate.

Groups compare their results. Results should be within the same order of magnitude. If one or more groups' results differ substantially, have them compare their process and estimates to see where they diverged.

DETERMINE A FACTOR OF SAFETY

You have now estimated the actual live load on your classroom floor right now. We know that the floor is currently supporting about that much weight.

How much extra weight do you think the floor is capable of supporting before it collapses? 100 pounds? (Let's hope not!) 1000 pounds? 10,000 pounds?

- *Think about the worst case scenario for this room. What if we packed a many people as possible in here. Do you think that the floor would still hold? Why or why not?*
- *How do you think the engineers who worked on our school decided how strong this floor should be?* ◘: Q&A

Groups think about a reasonable scenario (one that could be expected given the function of the room) in which the greatest amount of load would be acting on the classroom floor. One of the questions they may want to address is: how many more people or pieces of furniture could be reasonably fit into the room?

- *If you were an engineer, would you design for this worst case scenario? Or would you add a **factor of safety** to make extra sure that the building is safe? Remember, if you* *design a building so that it only holds as much as the maximum anticipated load, all it would take is one extra person for the structure to fail!*

- *You may be wondering: why do engineers even bother with a factor of safety? Why don't they just make the building as strong as it can possibly be?* ⭘: Q&A

Students discuss structural safety and decide upon a reasonable factor of safety.

Students multiply their live load estimations by their factor of safety to determine their design load specifications.

PRESENT

Groups discuss their process and present their results and reasoning to the rest of the class. Groups' figures are likely to vary widely – encourage discussion as to why each group feels their design load is justified.

COMPARE THE RESULTS TO CODES

*For school classrooms, the **Uniform Building Codes** mandate that the floors must be able to support a minimum of 40 **pounds per square foot** (40 p.s.f.).*

- *What does this mean?* ⭘: Q&A
- *How can we go about converting the design load you calculated into p.s.f. so you can compare your guess to the code?*

In their groups, students measure the dimensions of the classroom to determine the area.

Groups divide their design load figure by the square footage of the classroom to get their own p.s.f. strength rating.

Students compare their own p.s.f. rating to the code.

- *Did your calculations call for the floor to be stronger or weaker than the code?*

Now that we know the code, we can infer the minimum amount of load the floor of our classroom must be able to support. Remember that the code only specifies a minimum strength – our floors could support more than 40 p.s.f. but not less. Of course, we would never want to approach the minimum load limit – that would be courting disaster!

Groups multiply the area of the classroom by 40 to estimate the total minimum load that the floor of the classroom can support.

REFLECTION

- *Are you surprised by the difference between your calculations and the actual strength standards?*
- *If there is a large discrepancy, why do you think that is?*
- *Given what you know about the minimum p.s.f. rating for your classroom, do you feel confident in the structure of your school? Why or why not?*
- *What are some types of buildings that might require higher p.s.f. ratings than school buildings?*
- *How well did you meet your challenge? What would you do differently next time?*

EXTENSIONS AND VARIATIONS

- Have students consider what would happen if they all started to jump up and down. How would that change the live load on the floor? Engineers apply a **Dynamic Load Factor** to moving loads. The factor they use is 2, essentially doubling the load at rest to account for the impact of the moving load on the structure. Have students use the Dynamic Load Factor to calculate the total live load on your floor if all of them jumped at once.
- Students research the Uniform Building Code p.s.f. ratings for buildings types and explain the reasons for the different strength ratings.
- With the help of *Why Buildings Fall Down* (see **Resources**), groups research actual structural disasters to determine what went wrong and how they might have been prevented. Were the codes not followed in these cases? Or were they inadequate?

MIDDLE SCHOOL STANDARDS

Science

- Science as Inquiry (A)
- Physical Science (B)
- Science and Technology (E)
- Science in Personal and Social Perspectives (F)

Social Studies

- Science, Technology, and Society

Language Arts

- Speaking, Listening, and Viewing (E3a, b, c)
- Conventions, Grammar, and Usage of the English Languages (E4a, b)

Math

- Number and Operations Standard
- Algebra
- Measurement
- Data Analysis and Probability Standard
- Reasoning and Proof

Technology

- The Nature of Technology (1, 2, 3)
- Design (8, 9, 10)
- Abilities for a Technological World (11, 12, 13)
- The Designed World (16, 19, 20)

A Lively Loaded Room

MOTIVATION

- *Assuming that this scale is accurate, is it showing my true weight?*
  The scale is not showing your "true" weight because it is including the weight of your clothes, though this would make a difference only in more accurate bathroom scales.
- *Is there a limit to how much weight I can carry onto this scale?*
  The limit would be defined by how much weight you can physically carry, which is probably less than the upper limit of the scale itself.
- *What is the minimum reading the scale can have with me on it?*
  You can estimate that your clothes weigh 1-3 pounds and subtract that number from the reading.
- *If engineers were to design a scale specifically for me and anything I can carry, what is the range of weight readings the scale should have (assuming my weight stays constant)?*
  The answer will be based on your individual weight and estimated strength. For example, if you weigh 180 lbs. and estimate that you can carry 100 lbs., then the scale should be designed to register between 180 and 280 lbs.
- *Let's start at the bottom. What is the absolute minimum amount of load acting on our school building?*
  The minimum amount of load that could theoretically be acting on the school building is the weight of the building itself. If the building were completely empty, it would still have to support its own weight.
- *Why do you think it is called the dead load?*
  This load is called the dead load because it is a static, unchanging figure (unless the structure of the building is altered).
- *Now let's concentrate on our classroom. What are the forces acting as dead load on the classroom floor?*
  The dead load on the classroom floor would be the weight of the floor itself. The weight of the classroom walls are probably distributed to supporting pillars or walls on the lower level rather than the floor.
- *What objects in our classroom are part of the live load?*
  The live load would be everything that is inside the room that is not part of the structure of the building, including people, furniture, etc.

A Lively Loaded Room

- *Why do you think it is important for engineers to distinguish between live loads and dead loads?*

  It is very important for engineers to distinguish between live loads and dead loads when calculating how much total load a building needs to be able to support. While the dead load is constant, the live is variable, and depending on the type of building and its function, the live load can vary considerably. The anticipated live load also gets multiplied by a factor of safety – because the consequences of structural failure are disastrous, a building is always designed to support many times more than the anticipated live load.

ESTIMATE THE LIVE LOAD

- *How should we estimate the weight of all the people?*

  In order to estimate the weight of all the people in the room, recommended that students come up with an average student weight and multiply it by the number of students in the classroom (as opposed to weighing each student separately, which is time-consuming and can be uncomfortable for students who are sensitive about their weight.

- *How should we estimate the weight of all the desks and other furniture?*

  One way to weigh the desks is to have someone hold one and step on the scale. The weight of the desk is the figure registered by the scale minus the student's weight. For larger desks, it may take two people standing on two scales to hold them up, but the concept is the same. For very large items such as bookcases, you may need to estimate without weighing.

- *How should we estimate the weight of all the books?*

  Students can come up with an estimated average book weight by stacking average-sized books onto the scale and then dividing to get an average book weight estimate. This is then multiplied by the estimate of the total number of books to get a figure.

DETERMINE A FACTOR OF SAFETY

- *How do you think the engineers who worked on our school decided how strong this floor should be?*

  The engineers who worked on the school followed the **building codes** for your area. Some aspects of the code differ from city to city, while others are consistent at the state or national level. Most structural safety codes, called **Uniform Building Codes** (U.B.C.), are set by the federal government, though some areas can have codes which are more stringent. The codes establish the minimum amount of weight that the floors of a structure need to be able to support – engineers can choose to make the structure stronger than code (and they often do) but they cannot make it weaker. The codes are determined using a **factor of safety** calculation.

A Lively Loaded Room

- *You may be wondering: why do engineers even bother with a factor of safety? Why don't they just make the building as strong as it can possibly be?*

  Engineers must weight structural strength and safety against other factors, such as space and cost. Overly reinforced buildings cost more to build and extra structure can restrict interior space and add to the dead load of a building. After a certain point, adding more structure may not actually increase strength because of the dead-load factor. The factor of safety calculations and the codes are designed to make buildings as safe a possible while still being practical and affordable.

COMPARE RESULTS TO CODE

- *What does this mean?*

  It is important for students to understand that the 40 p.s.f. specification does *not* mean that each square foot can hold only 40 pounds. What is means is that if the floor were uniformly covered with 40-lb. weights on every square foot, it must be strong enough to support that weight. It may be helpful to use the bathroom scale to weigh out a 40 lb. stack of books and have students imagine an identical stack placed on every square foot of the room. You may want to ask students if they can figure our why structural strength codes specify load in proportion to area.

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name(s) date

A Lively Loaded Room
Estimating Classroom Live Load

Activity Sheet

Your challenge is to determine the **design live load** to use to build a new classroom.

First, estimate the **actual live load** on the classroom floor:

- List the items that are part of the live load in the table below.
- Weigh one of each type of item to determine its unit weight.
- Multiply the unit weight by the quantity of the item.
- Add up the total weights of all the items. For more space, use the back of this sheet. If the item is too big to lift, you may have to estimate its weight.

ACTUAL LIVE LOAD

ITEMS	QTY	UNIT WGT	TOTAL WGT
		TOTAL EST. LIVE LOAD	

Congratulations! You have estimated the **actual live load** on your classroom floor. But is that the load you want to design for? Don't forget to multiply the actual live load in your classroom by some **factor of safety** to account for visitors or anything else you may add to the room. As you think about this, however, consider that as you design for higher possible live loads, you make your structure more expensive. You don't want the most expensive classroom in the world, but you also don't want any students falling through the floor!

What factor of safety do you think is appropriate?

Factor of Safety

Calculate your **design live load** (= actual live load x factor of safety).

Design Live Load

name(s) date

A Lively Loaded Room

Group Rubric

	Excellent	Good	Satisfactory	Needs Improvement	Inadequate
Understanding of Math Concepts	The group derived well thought-out estimates and innovative approaches to measuring activities and made accurate calculations and measurements.	Estimates were reasonable, calculations and measurements were mostly accurate.	Estimates were based on a tentative understanding of the concepts, calculations and measurements had some errors.	Estimates were based on a cursory understanding of the concepts involved; the group had trouble understanding the processes behind the operations, made many errors.	Estimates were not developed based on any adequate understanding or process of logical reasoning and calculations, and measurements were grossly inaccurate or missing.
Understanding of Technology Concepts	The group demonstrated thorough understanding of the concepts of live load, dead load and design load and proposed a reasonable factor of safety.	The group demonstrated adequate understanding of the concepts of live load, dead load and design load and proposed a plausible factor of safety.	The group demonstrated passable understanding of the concepts of live, dead load and design load, but did not include all appropriate items in its calculations and proposed a factor of safety that was not entirely plausible.	The group had trouble with the concepts of live load and dead load and did not include the appropriate items in their calculations, had trouble understanding the concept of design load and came up with an implausible factor of safety.	The group showed little understanding of the concepts of live load and dead load and made little attempt to demonstrate understanding of the concept of design load.
Group Work Skills	Group members cooperated effectively and ensured that all members were significantly involved in group activities; all members of the group demonstrated thorough understanding of the concepts.	Group members cooperated effectively and ensured that all members were significantly involved in group activities; all members of the group demonstrated adequate understanding of the concepts.	Some group members were excluded from or declined to participate in certain activities, though most of the group demonstrated understanding of the concepts.	The group engaged in little cooperation and most members did not participate adequately in the activities, though some members of the group demonstrated understanding of the concepts.	Little evidence of group collaboration, or group members were disruptive to other groups; members did not demonstrate their understanding of the concepts.
Communication and Presentation	The group prepared an exceptional presentation and was able to clearly and persuasively explain the reasoning behind the its activities; the group used very interesting and relevant visual aids to enhance the presentation.	The group prepared an engaging presentation and was able to adequately explain the reasoning behind its activities; The group used interesting and relevant visual aids to enhance the presentation.	The group prepared a satisfactory presentation and was able to adequately explain the reasoning behind its activities; the group used some interesting or relevant visual aids to enhance the presentation.	The group prepared a less-than-satisfactory presentation and had difficulty explaining the reasoning behind the its activities; the group did not use interesting or relevant visual aids to enhance the presentation.	The group did not have a coherent presentation and did not attempt to explain its activities.