Best Practices in Designing and Implementing Courses
which combine Biology and Mathematics

Lowering the Activation Energy: Making Quantitative Biology more Accessible

QUBES @ NCSU

June 20, 2016

CapstoneInstitute
at Howard University

Yikes, Math Phobia?!?

OH NO! NOT MATH!!

Factors that Influence How We Work

thoughts ↔ emotions

behaviors and choices ↔ feelings and sensations
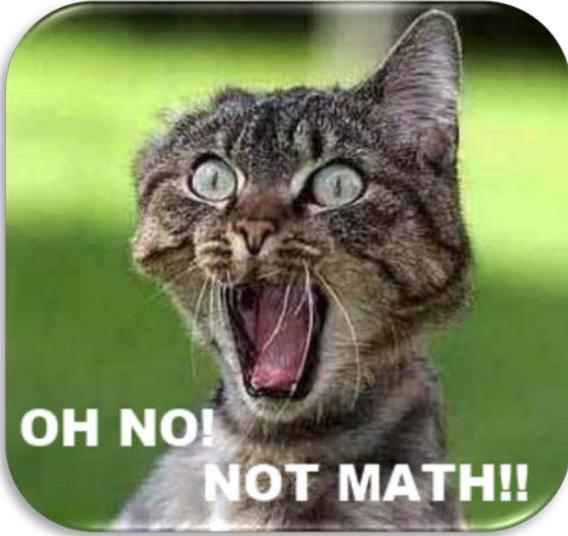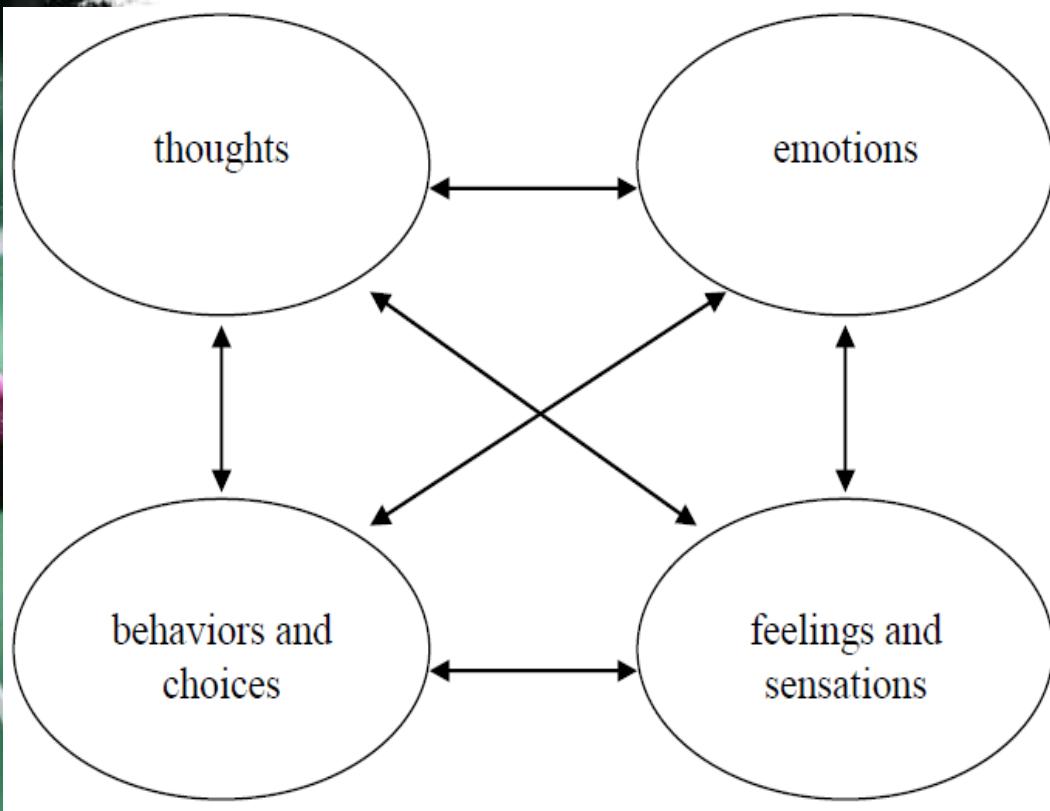
Strategies

- Student learning empowerment

- Backward design process

- Research teams

http://faculty.mc3.edu/cvaughen/mathconfidence/index.html
https://www.qriyo.com/blog/index.php/2016/02/19/a-love-potion-for-math-haters/

Student Learning Empowerment Strategies

1. Self-efficacy
   - *Confidence that one can do what it takes to accomplish the desired outcome*
   - *Students know they have the skills to do the task*

2. Incremental ability beliefs
   - *Focus on intelligence as malleable rather than intelligence as fixed*
   - *Students know that they can develop their talent*

3. Self-regulated learning
   - *Goal setting, monitoring and assessing one's own learning*
   - *Students have the necessary habits to succeed*

Empowerment: Self-Efficacy Strategies

- Compliment students on the skills they **develop**

- Help students practice lack-of-effort explanations for poor performance

- Promote recognition of **progress** during interactions

- Help students define and set goals

- Help students document their **growth**

- Use peer models

Empowerment: People with Incremental Ability…

- believe that intelligence is malleable.

- attribute success to effort.

- when faced with failure, are more likely to persist.
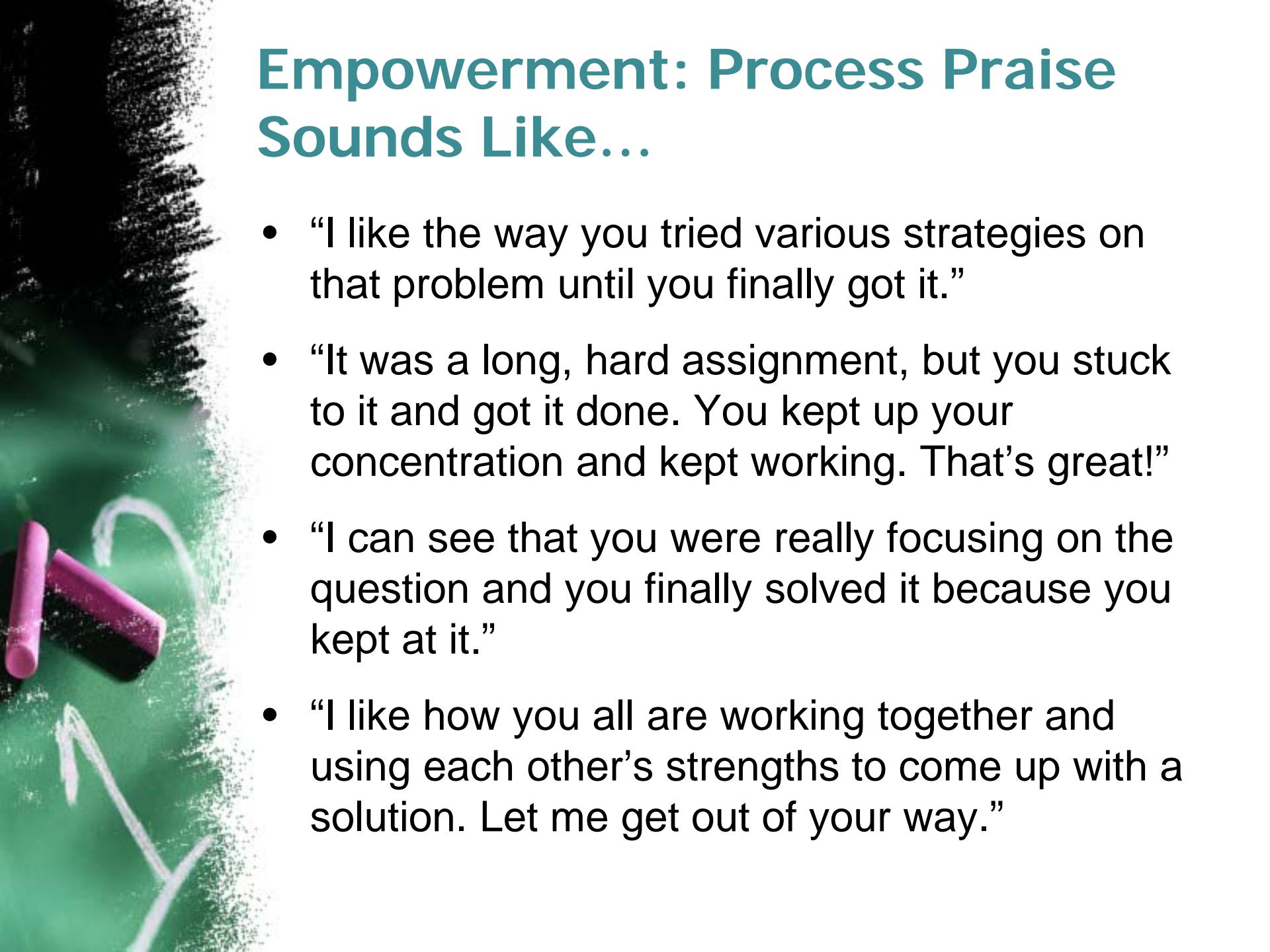
Empowerment: Process Praise Sounds Like…

- "I like the way you tried various strategies on that problem until you finally got it."

- "It was a long, hard assignment, but you stuck to it and got it done. You kept up your concentration and kept working. That's great!"

- "I can see that you were really focusing on the question and you finally solved it because you kept at it."

- "I like how you all are working together and using each other's strengths to come up with a solution. Let me get out of your way."

The Backward Design Process
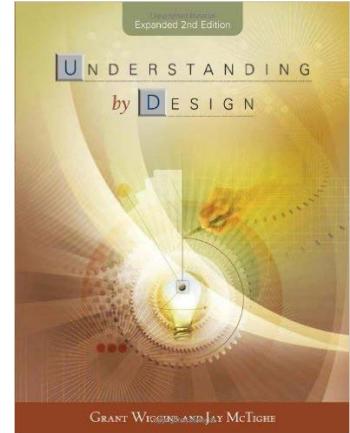
1. Identify desired results.

2. Determine acceptable evidence.

3. Plan learning experiences and instruction.

- *Understanding by Design* by Wiggins and McTighe

Research Teams

- Give students the social models that give insight on how to best function in a team
  - *Tuckman's stages of team development*
  - *Social styles model*

- Give teams specific feedback both in writing and orally on how to improve performance (this goes both ways)

- Rubrics for everything

- Team-reflections and self-reflections give each student key insights on how improve as well as how to develop hard and soft skills

A Research-Based Topics Course

for First-Year Students (1 credit hour)
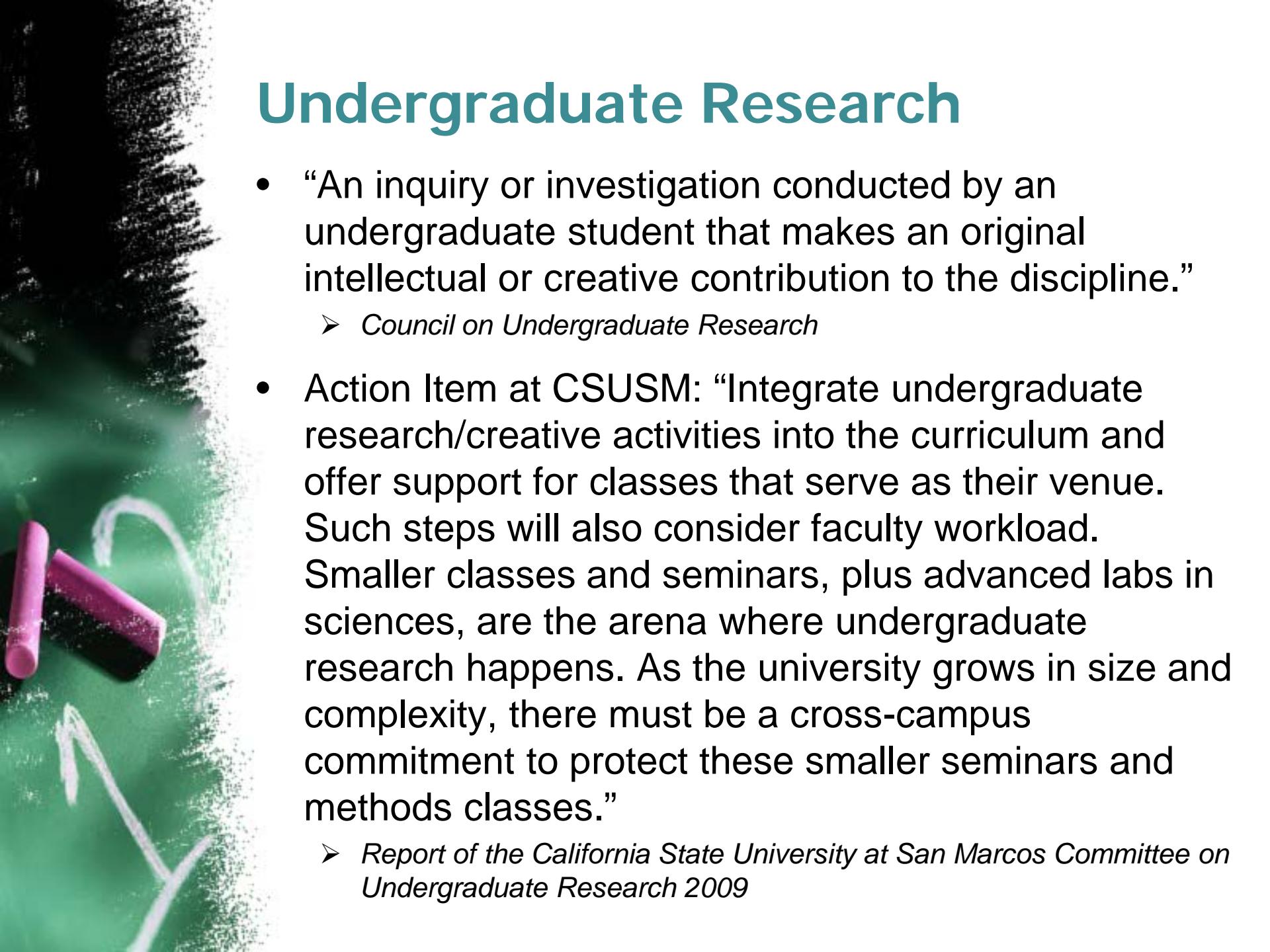
Undergraduate Research

- "An inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline."
  - ➢ *Council on Undergraduate Research*

- Action Item at CSUSM: "Integrate undergraduate research/creative activities into the curriculum and offer support for classes that serve as their venue. Such steps will also consider faculty workload. Smaller classes and seminars, plus advanced labs in sciences, are the arena where undergraduate research happens. As the university grows in size and complexity, there must be a cross-campus commitment to protect these smaller seminars and methods classes."
  - ➢ *Report of the California State University at San Marcos Committee on Undergraduate Research 2009*

Infusion of Your Research

- Goal
  - ➤ *Train students to become independent, innovative, and critically thinking scientists*
  - ➤ *Prepare students for productive careers in academic and other settings*

- Components
  - ➤ *Balance the cost to the faculty and the benefit to the student*
  - ➤ *Occurs during the school year, not the summer*
  - ➤ *Implement in classes for freshmen, sophomores, juniors, and seniors*
    - Team-teaching

Course Creation

- Idea
  - ➢ *Expose first-year students to applications of calculus in biology*

- Goals
  - ➢ *Train students to become independent, innovative, and critically thinking scientists*
  - ➢ *Prepare students for productive careers in academic and other settings*

- Challenges
  - ➢ *Students' course selection is limited*
  - ➢ *Exploring a topic that is of interest to students*
  - ➢ *Selecting appropriate mathematical content*
  - ➢ *Getting the students to work*
  - ➢ *Make it worth my while*

Topics Course: SIR Models

- Special Topics in Calculus (1-3 credit hours)
  - ➢ *Study of aspects or applications of calculus not covered in the standard calculus sequences. Topics will be announced. May be repeated. Prerequisite: Calculus I.*

- Four first-year students from biology, engineering, mathematics, and psychology
  - ✓ *Chose to study spread of infectious disease models*
  - ✓ *SIR = Susceptible, Infected, and Recovered*

- Grading
  - ➢ *Active Participation/Attendance = 50%*
  - ➢ *Final Project = 50%*

Preliminary Work

- Definitions and terminology

- Separable Differential Equations

- Solving Via MATLAB with Euler's Method

- Investigated qualitative features via pplane from Rice University

- http://math.rice.edu/~dfield/

- Read a published paper: "Numerical integration of population models satisfying conservation laws: NSFD methods" by Ronald Mickens. Journal of Biological Dynamics. October 2007

Reading Mickens' Paper: Students Provided Questions

- Why does there need to be a conservation law in a population? What is a conservation law in math?

- Can you explain equations 11 and 12, in fact the whole NSFD methodology section. I think I might have just been overwhelmed by the variables thrown out.

- So I read the paper twice and skimmed it once, this is a tough read. I mostly understand it until I get to part 2, NSFD methodology.

  - *There were many equations with the subscript k, but my question is whether this k still represents birth rate or n?*

  - *I don't know what a non-standard finite difference is.*

Extending the Learning

- Coordinated Dr. Mickens' visit to campus with internal funds so students could meet with him and talk "math" with him

- Discussed the Tuskegee Syphilis Experiment and watched HBO film *Miss Evers' Boys*
  - *Conducted between 1932 and 1972 in Tuskegee, Alabama, by the US Public Health Service*
  - *Recruited about four hundred black men with syphilis to research natural progression of the untreated disease*
  - *Never told if they had syphilis nor were they treated for it*
  - *By 1969, one hundred men died and the disease spread to their families*

Final Project

- *In teams of 2*, students gave a PowerPoint presentation on a journal article that uses SIR model

- On Modeling SARS in Hong Kong. W. Shing et al. IJAM, 2003.
  - ➤ *Apply an SIR model to study the spread of the Severe Acute Respiratory Syndrome (SARS) in a housing complex in Hong Kong.*

- Genetic Diversity in the SIR Model of Pathogen Evolution. I. Gordo et al. PLoS One, 2009.
  - ➤ *Use an SIR model to assess the levels and patterns of genetic diversity in pathogen populations.*

Student Feedback

- "I thought the class was very applicable to the real world; it brought Calculus alive to me. I could actually see a reason for what looked like chaos on the chalkboard and could actually use that in what I wanted to do after graduation. It was also neat to be able to incorporate so many different areas of study, especially biology and calculus, and see how they fit together while still in school."

- The topics course was a great experience to see math as an applied science with a real life application. The project at the end of the course was great for working in a group to understand the spread of a disease.

A Team-taught Topics Course

on Mathematical Modeling in Synthetic Biology (1 credit hour)
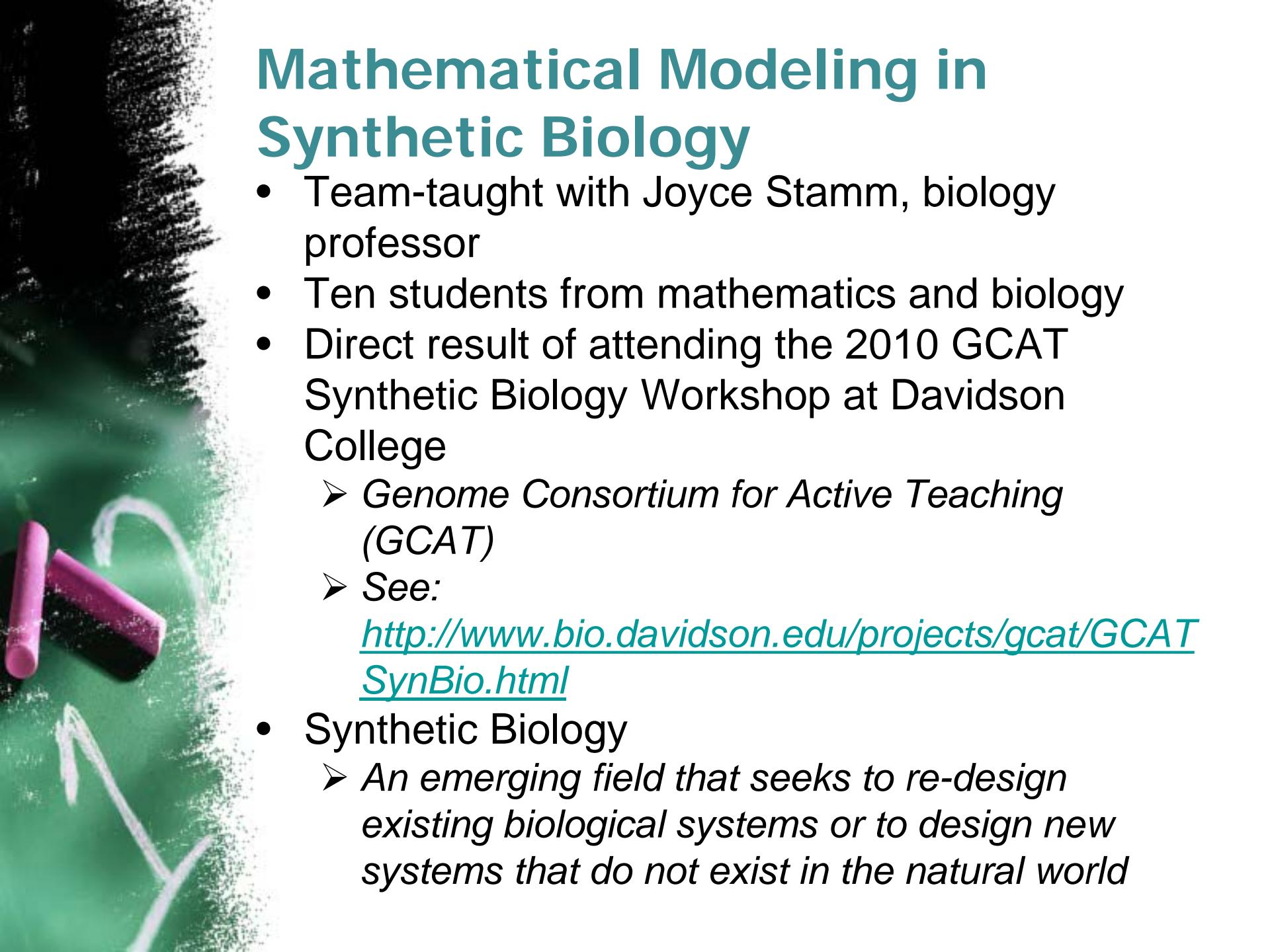
Mathematical Modeling in Synthetic Biology

- Team-taught with Joyce Stamm, biology professor
- Ten students from mathematics and biology
- Direct result of attending the 2010 GCAT Synthetic Biology Workshop at Davidson College
  - *Genome Consortium for Active Teaching (GCAT)*
  - *See: http://www.bio.davidson.edu/projects/gcat/GCATSynBio.html*
- Synthetic Biology
  - *An emerging field that seeks to re-design existing biological systems or to design new systems that do not exist in the natural world*
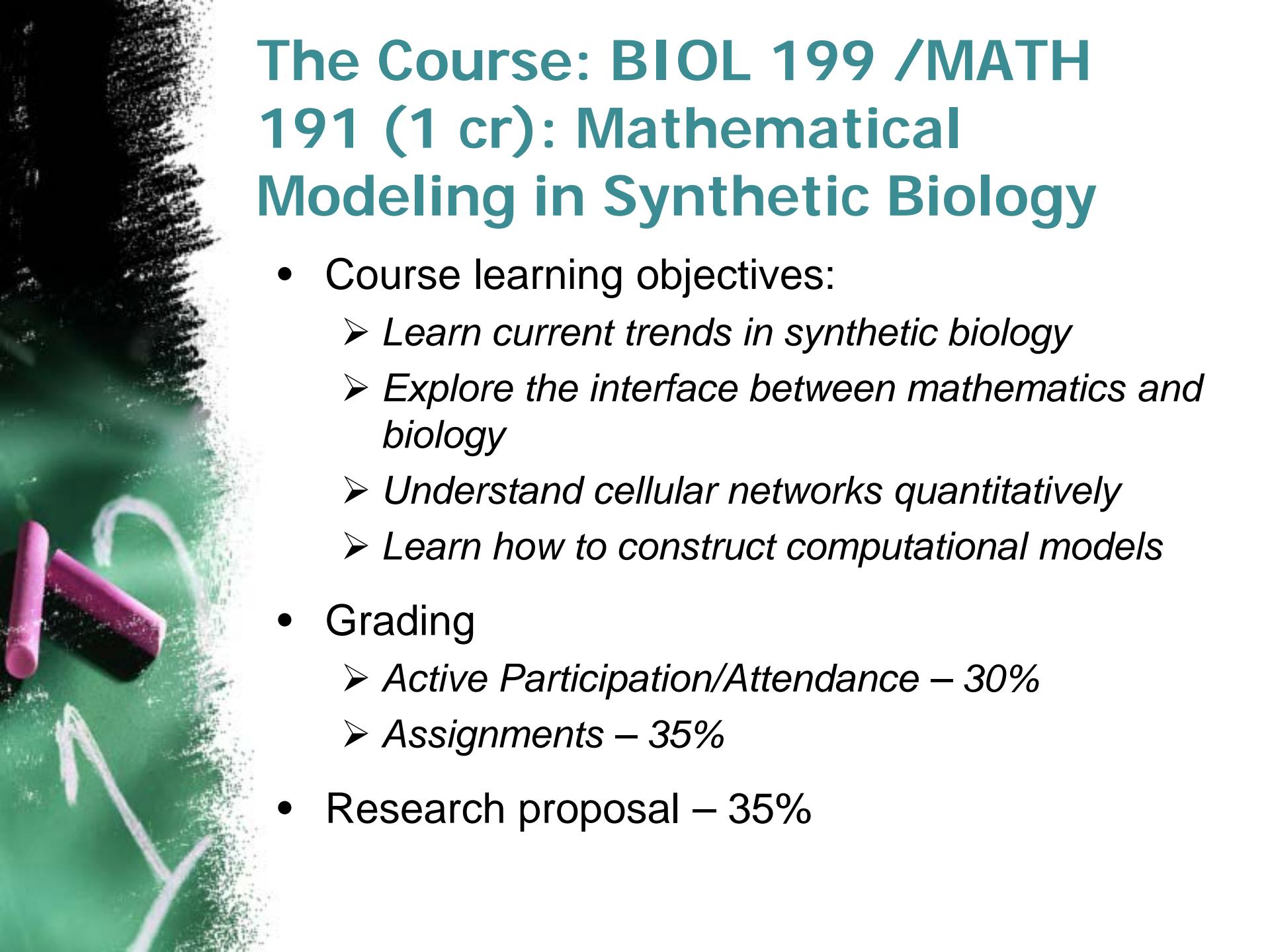
The Course: BIOL 199 /MATH 191 (1 cr): Mathematical Modeling in Synthetic Biology

- Course learning objectives:
  - *Learn current trends in synthetic biology*
  - *Explore the interface between mathematics and biology*
  - *Understand cellular networks quantitatively*
  - *Learn how to construct computational models*

- Grading
  - *Active Participation/Attendance – 30%*
  - *Assignments – 35%*

- Research proposal – 35%

Week	In class	Reading	Assignment
1	Course overview	*A Life of Its Own,* The New Yorker	Submit 3 questions about the reading before class
2	Discuss the article *A Life of Its Own*	*Meeting Report: Synthetic Biology Jamboree for Undergraduates,* Cell Biology Education Browse iGEM 2009 website: http://2009.igem.org/	Submit 3 questions about the reading/website before class
3	Discuss the meeting report and iGEM website Students give 30 second blurb on one interesting iGEM project	*Engineering bacteria to solve the Burnt Pancake Problem*, J. Biol. Eng.	Submit 3 questions about the reading before class
4/5	Discuss the Burnt Pancake paper	Read about Cambridge 2009 iGEM http://2009.igem.org/Team:Cambridge *Triggering Pigment Production in E. Coli*	
6/7	Discuss the pigment production project	Explore iGEM website and pick a project to present	Prepare 10-15 minute presentation on iGEM project
8/9	Presentations of iGEM projects		Written assignment – selected project (to continue exploring)
10	Arrive at consensus about area to explore		
11-13	Discuss topics chosen by class consensus		
14-15	Design research project		Write proposal to
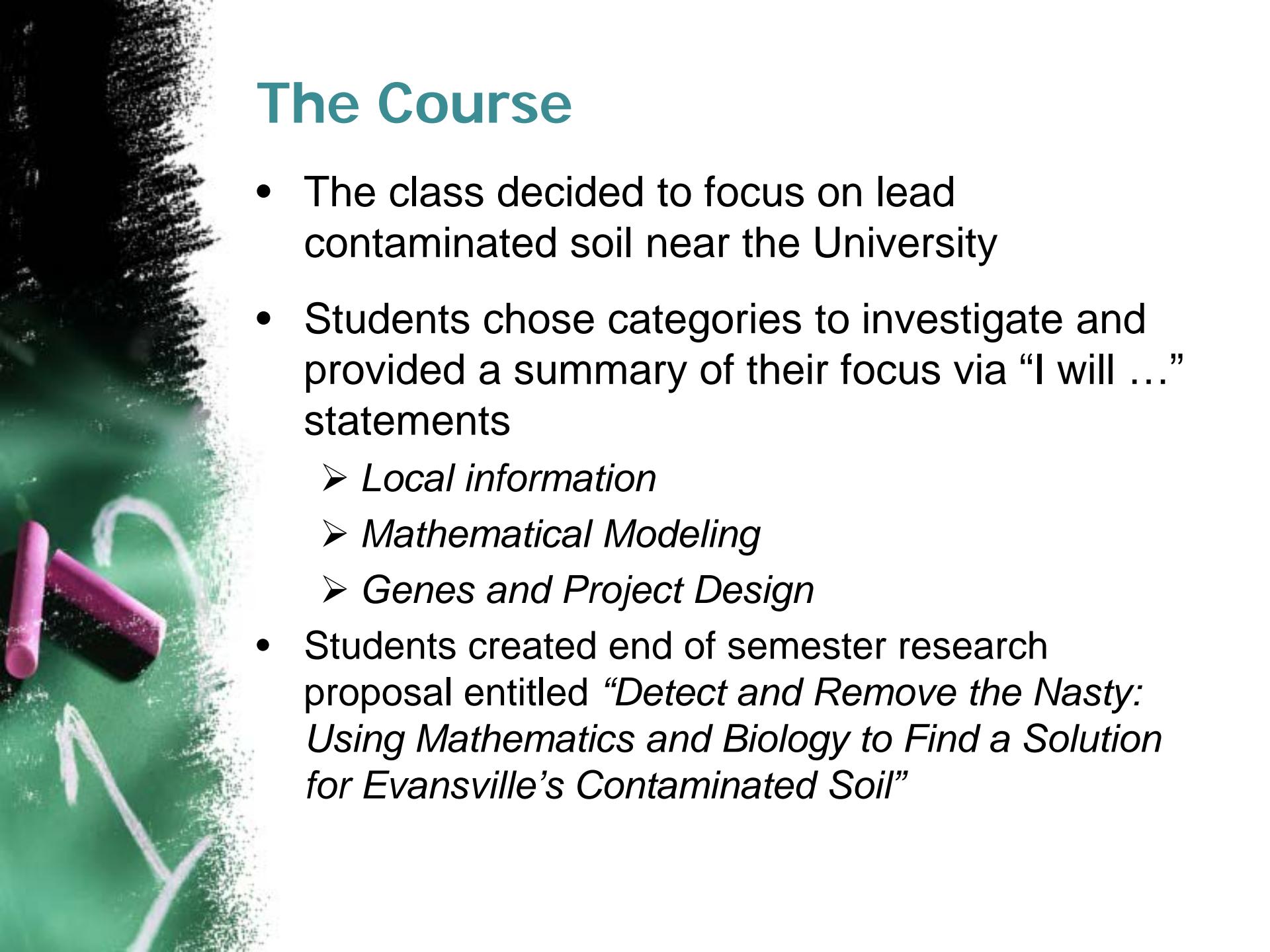
The Course

- The class decided to focus on lead contaminated soil near the University

- Students chose categories to investigate and provided a summary of their focus via "I will …" statements
  - ➢ *Local information*
  - ➢ *Mathematical Modeling*
  - ➢ *Genes and Project Design*

- Students created end of semester research proposal entitled *"Detect and Remove the Nasty: Using Mathematics and Biology to Find a Solution for Evansville's Contaminated Soil"*
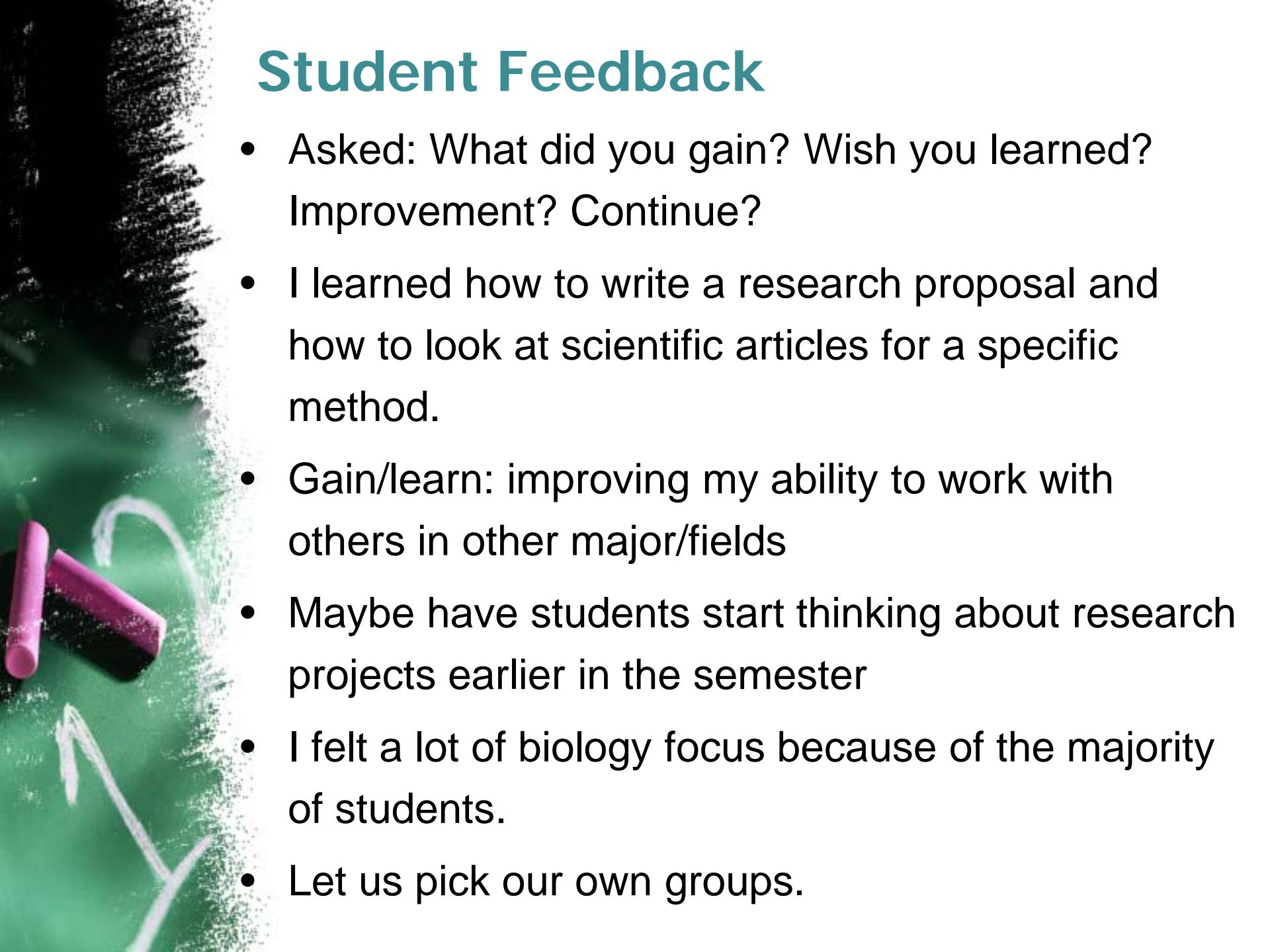
Student Feedback

- Asked: What did you gain? Wish you learned? Improvement? Continue?

- I learned how to write a research proposal and how to look at scientific articles for a specific method.

- Gain/learn: improving my ability to work with others in other major/fields

- Maybe have students start thinking about research projects earlier in the semester

- I felt a lot of biology focus because of the majority of students.

- Let us pick our own groups.

A Research-Based Course

for Advanced Undergraduates and Beginning Graduate Students (3 credit hours)

Course Overview

Goal = Create Researchers

> ➢ "To successfully undertake careers in research after graduation, students will need scientific knowledge, practice with experimental design, quantitative abilities, and communication skills."
> BIO2010

Learning Goals

✓ *Gain a clear understanding of the interplay between mathematics and biology*

✓ *Develop and analyze mathematical models that accurately describe biological processes*

✓ *Use MATLAB/OCTAVE and LaTeX*

✓ *Improve skills in scientific writing and presenting*

Research-Based Course

MATH 192/450 Topics in Applied Mathematics (3 cr)

- ✓ *A course in mathematical biology. The course covers applications of difference equations, differential equations, and dynamical systems theory to biological problems. Topics include population dynamics, reaction kinetics, diseases, and cellular dynamics. Prerequisite: Differential Equations*

- Grading
  - ✓ *Homework = 70%*
  - ✓ *Final Project = 30%*

Course Project

- Utilize mathematics to investigate a biological system

- Must be research-based (with instructor approval)

- Length of final report > 10 pages

- Given explicit order of project

- Format is based upon the format of a journal article depending on student's field

- Projects expose students to a variety of research

- The teacher is the "coach" through the experience
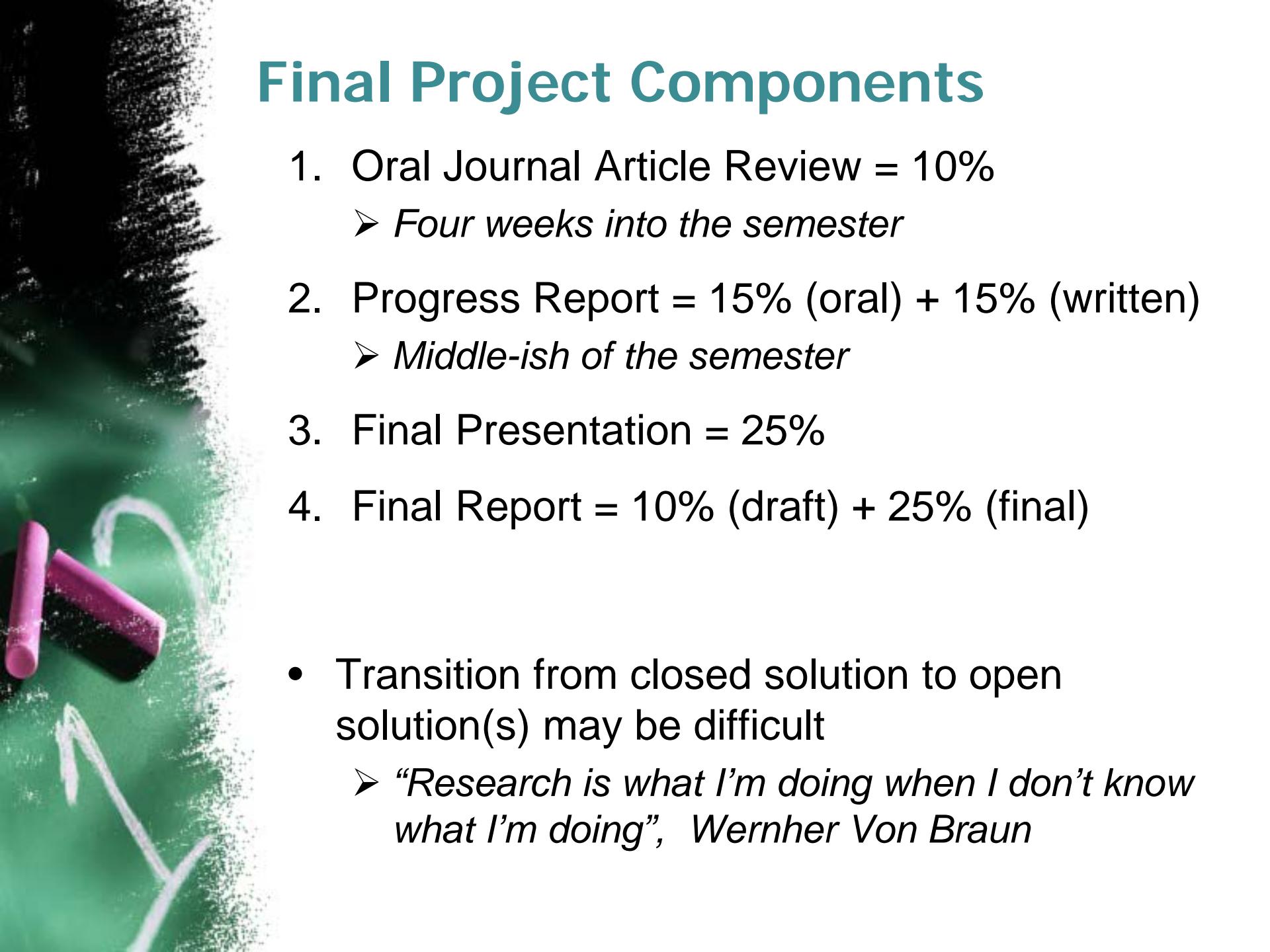
Final Project Components

1. Oral Journal Article Review = 10%
   - ➢ *Four weeks into the semester*

2. Progress Report = 15% (oral) + 15% (written)
   - ➢ *Middle-ish of the semester*

3. Final Presentation = 25%

4. Final Report = 10% (draft) + 25% (final)

- Transition from closed solution to open solution(s) may be difficult
  - ➢ *"Research is what I'm doing when I don't know what I'm doing", Wernher Von Braun*

Cultivating a Research-oriented Mindset in the Homework

- For homework, students read a paper, discuss its components, and then re-do the numerical computations

- Example:
  - ✓ *Read: Robert May. Biological Populations with Nonoverlapping Generations: Stable Points, Stable Cycles, and Chaos. Science, Vol. 186, No. 4164 (Nov. 15, 1974), 645-647.*
  - ✓ *Discuss the dynamics of*

  $N_{t+1} = N_t \exp[r(1 - N_t/k)]$ and $N_{t+1} = N_t[1 + r(1 - N_t/k)]$

  - ✓ *Why do you **think** this proposed model may or may not be better than…What do the graphs **mean**? Explain using complete sentences.*

Students' Research Perceptions

- In this assignment, you will read one article and watch two videos about Mathematical Biology and write reviews on each. The review should include your thoughts, opinions and insights as well as to their main results, findings, approach, implications, limitations, questions for future research, etc. Do not simply regurgitate when you have seen or read. Rather, submit a high-quality review paper that demonstrates synthesis, discernment, and an analysis. Each review should be at least one page long.

  - *Read Why Is Mathematical Biology So Hard? by Michael C. Reed.*

  - *Watch Modeling Flocks and Swarms by Leah Edelstein-Keshet.*

  - *Select one video of your choice from the Mathematical Biosciences Institute at http://beta.mbi.ohio-state.edu/video/.*

Embed Project into Homework

- Example: Create and *attempt to* implement a numerical scheme that models a biological system in your project. Include the equation(s), a table of parameters, and a reference. Your output should include relevant graphs with appropriate labels. Include a bibliography at the end. Note that your code may not run properly but you will be evaluated on proper components. Write up all of these aforementioned items using either Microsoft Word (Math 192) or LaTeX (Math 450).

Presentation Rurbric

ORAL PRESENTATION CHECKLIST   Name(s)_____

1. INTRODUCTION:			
a. Introduce self	0	1	
b. Provide topic overview	0	1	2
c. State major results	0	1	2

2. PRESENTATION:			
a. Present correct assigned content	0	2	4
b. Communicate with correct mathematical reasoning	0	2	4
c. Present adequate support for conclusions	0	1	2
d. **CONCLUSION:** Review significant results	0	1	2

Presentation Rubric Continued

3. ORGANIZATION AND STYLE:

a. Timing	0	1	2
b. Quality of visuals	0	1	2
c. Clarity of communication, eye contact	0	1	2
d. Apparent preparation	0	1	2

BONUS: Creativity, appropriate humor	0	1	2

General comments: Presentation Grade_____/25 ($\leq$ 25)

Student Feedback

- Learned how to "talk math"

- Gained real experience in research in mathematical biology

- Acquired scientific writing skills

- Obligation to produce papers of high quality for scientific community

- Students said they enjoyed the class and have continued in their research

A Team-Centered Seminar Course

for Undergraduate Math Majors and Minors
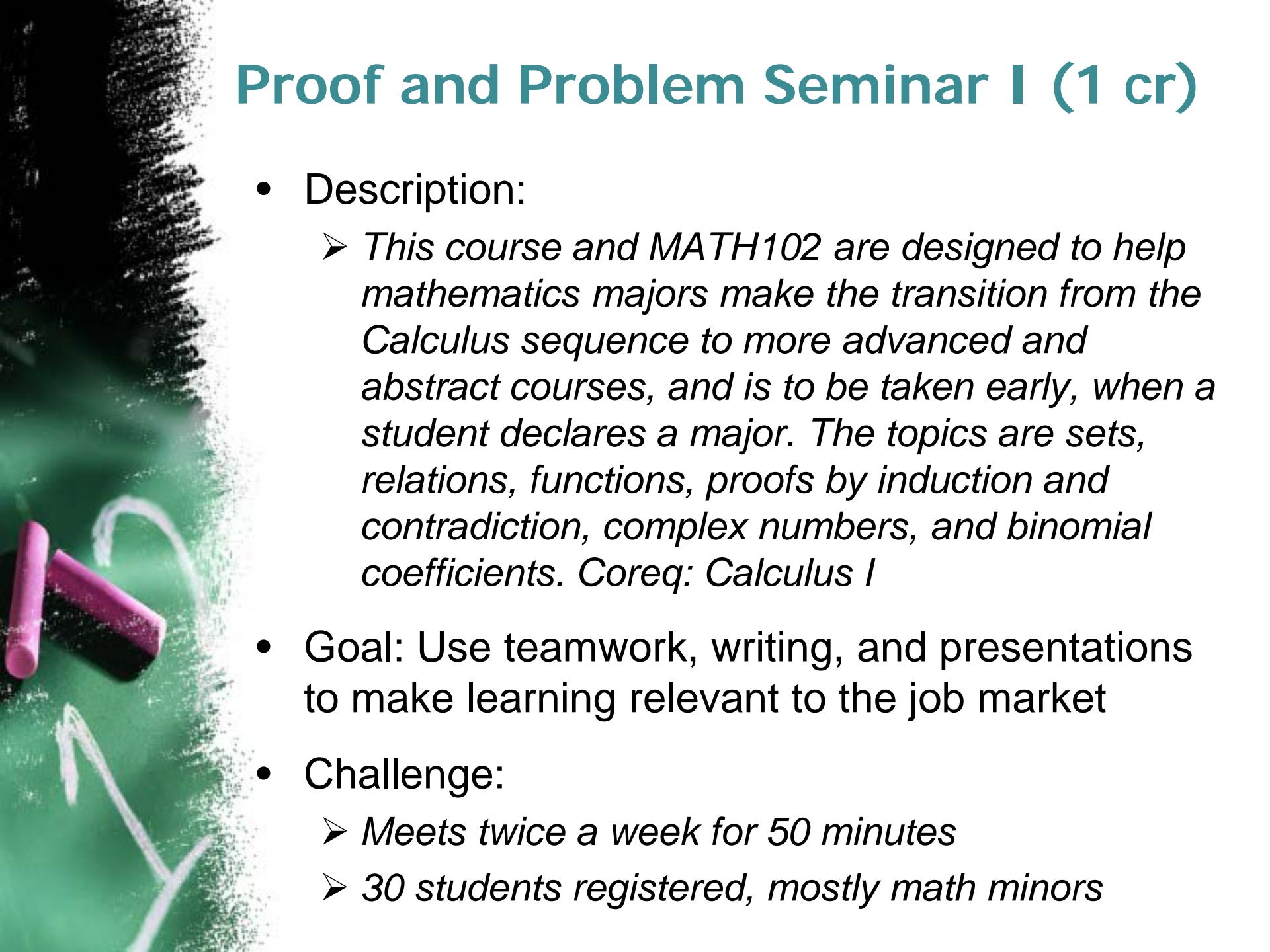
Proof and Problem Seminar I (1 cr)

- Description:
  - *This course and MATH102 are designed to help mathematics majors make the transition from the Calculus sequence to more advanced and abstract courses, and is to be taken early, when a student declares a major. The topics are sets, relations, functions, proofs by induction and contradiction, complex numbers, and binomial coefficients. Coreq: Calculus I*

- Goal: Use teamwork, writing, and presentations to make learning relevant to the job market

- Challenge:
  - *Meets twice a week for 50 minutes*
  - *30 students registered, mostly math minors*

SACNAS Summer Leadership Institute: Dr. Joe Garcia

- The institute prepares participants to assume leadership roles in the global scientific community by offering advanced strategic trainings that develop critical leadership skills.

- "…get some training in project management…"

Project Management Fundamentals

- A project has a finite timeline that results in a product, service, or result.

- Project management is the application of skills, tools, and knowledge to meet project requirements.

- A project team is responsible for planning and executing the project.
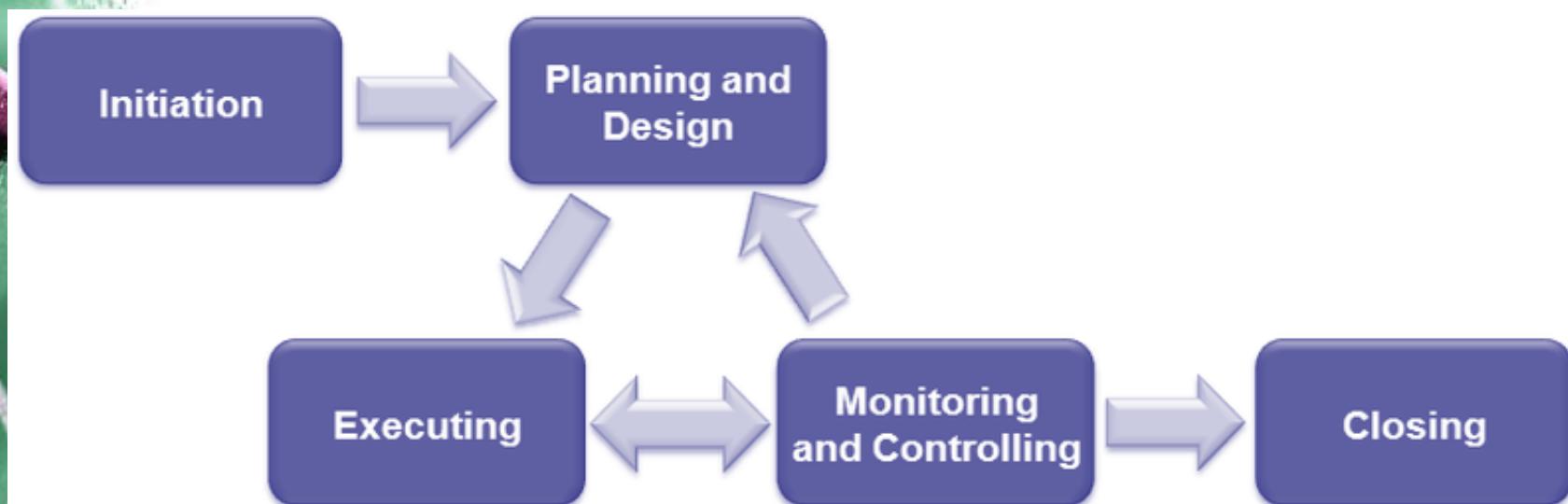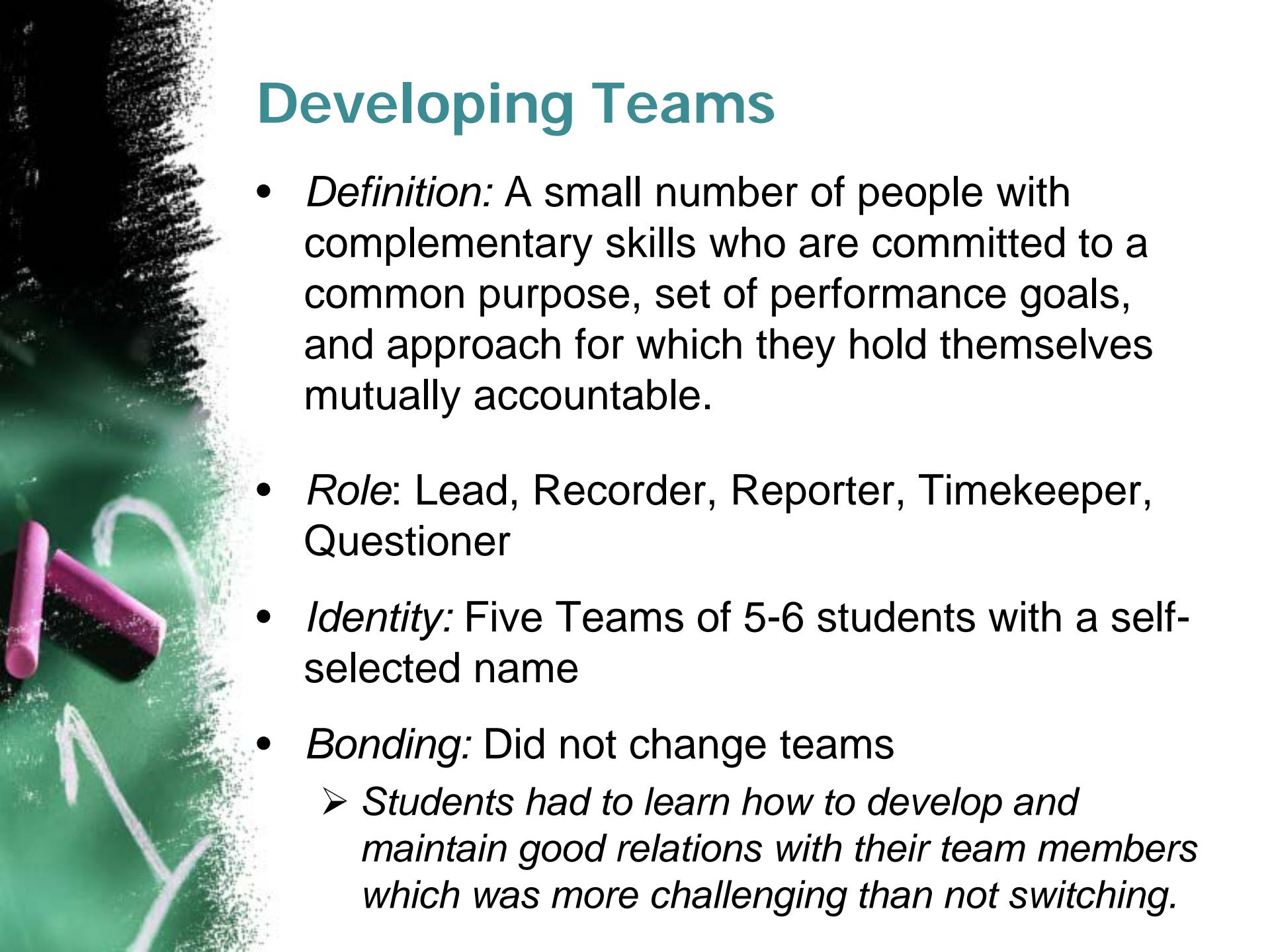
Developing Teams

- *Definition:* A small number of people with complementary skills who are committed to a common purpose, set of performance goals, and approach for which they hold themselves mutually accountable.

- *Role*: Lead, Recorder, Reporter, Timekeeper, Questioner

- *Identity:* Five Teams of 5-6 students with a self-selected name

- *Bonding:* Did not change teams
  - ➤ *Students had to learn how to develop and maintain good relations with their team members which was more challenging than not switching.*

Stages of Team Development
Tuckman

- Forming
  - *Identify similarities*
  - *Developing trust*
- Storming
  - *Conflict and power and control issues*
  - *Expressing ideas, feelings, and opinions*
- Norming
  - *Agreement and consensus about roles and processes for problem solving*
  - *Focus on goal achievement*
- Performing
  - *Members find solutions to problems*
  - *Group has an identity and members are interdependent*
- Adjourning/Mourning
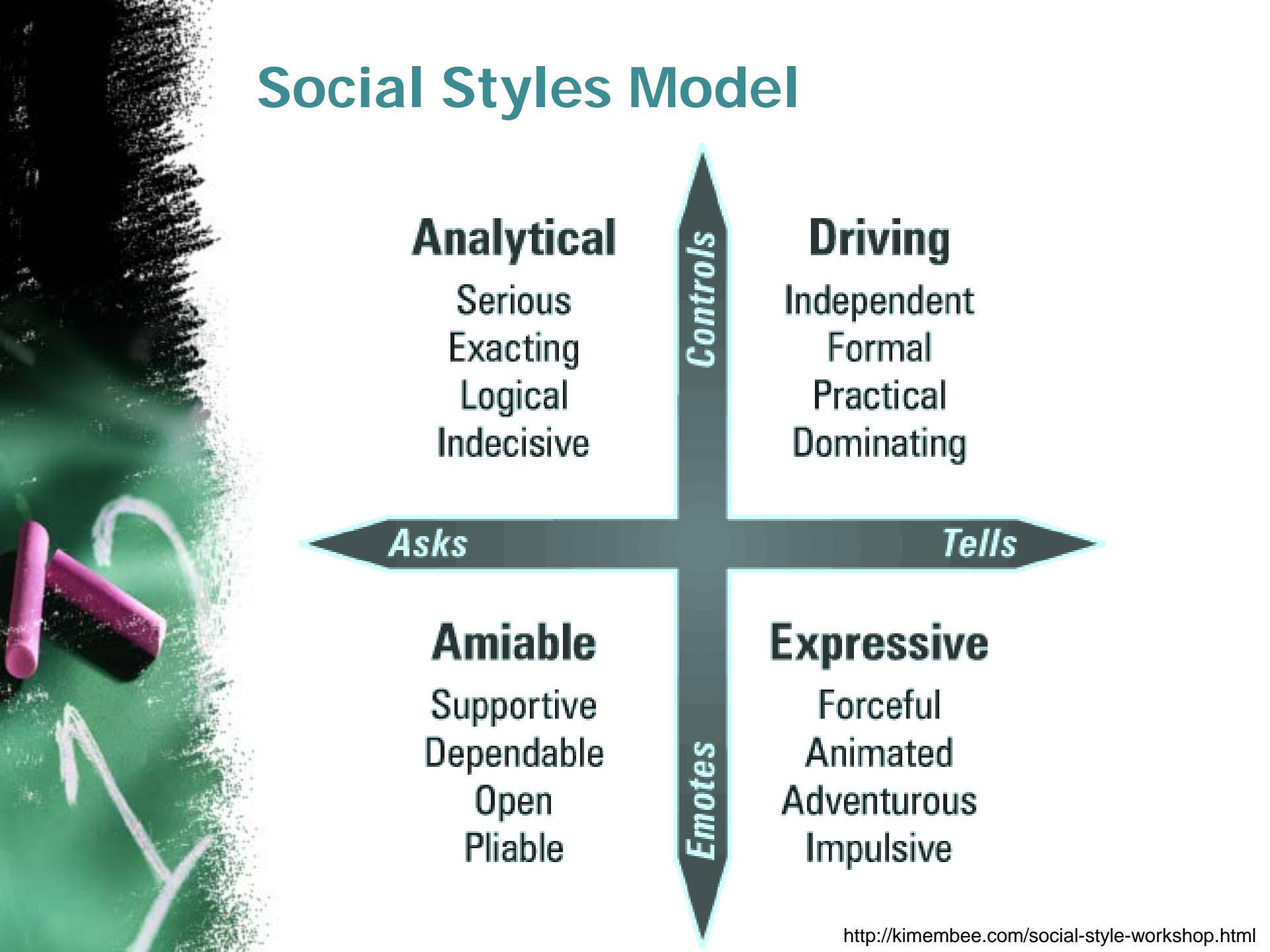
Social Styles Model

Analytical
Serious
Exacting
Logical
Indecisive

Driving
Independent
Formal
Practical
Dominating

Controls

Asks — *Tells*

Amiable
Supportive
Dependable
Open
Pliable

Expressive
Forceful
Animated
Adventurous
Impulsive

Emotes
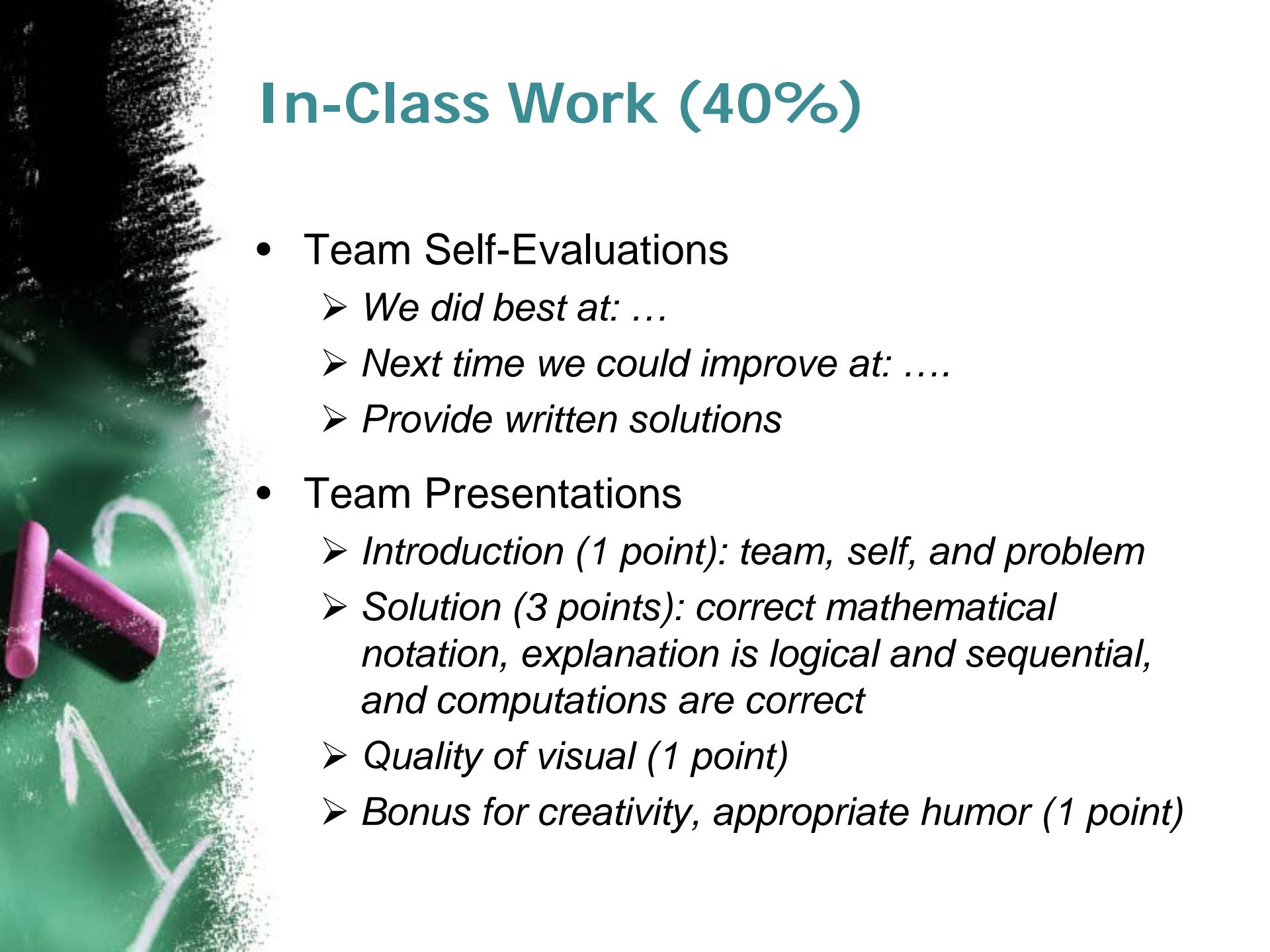
In-Class Work (40%)

- Team Self-Evaluations
  - ➤ *We did best at: …*
  - ➤ *Next time we could improve at: ….*
  - ➤ *Provide written solutions*

- Team Presentations
  - ➤ *Introduction (1 point): team, self, and problem*
  - ➤ *Solution (3 points): correct mathematical notation, explanation is logical and sequential, and computations are correct*
  - ➤ *Quality of visual (1 point)*
  - ➤ *Bonus for creativity, appropriate humor (1 point)*
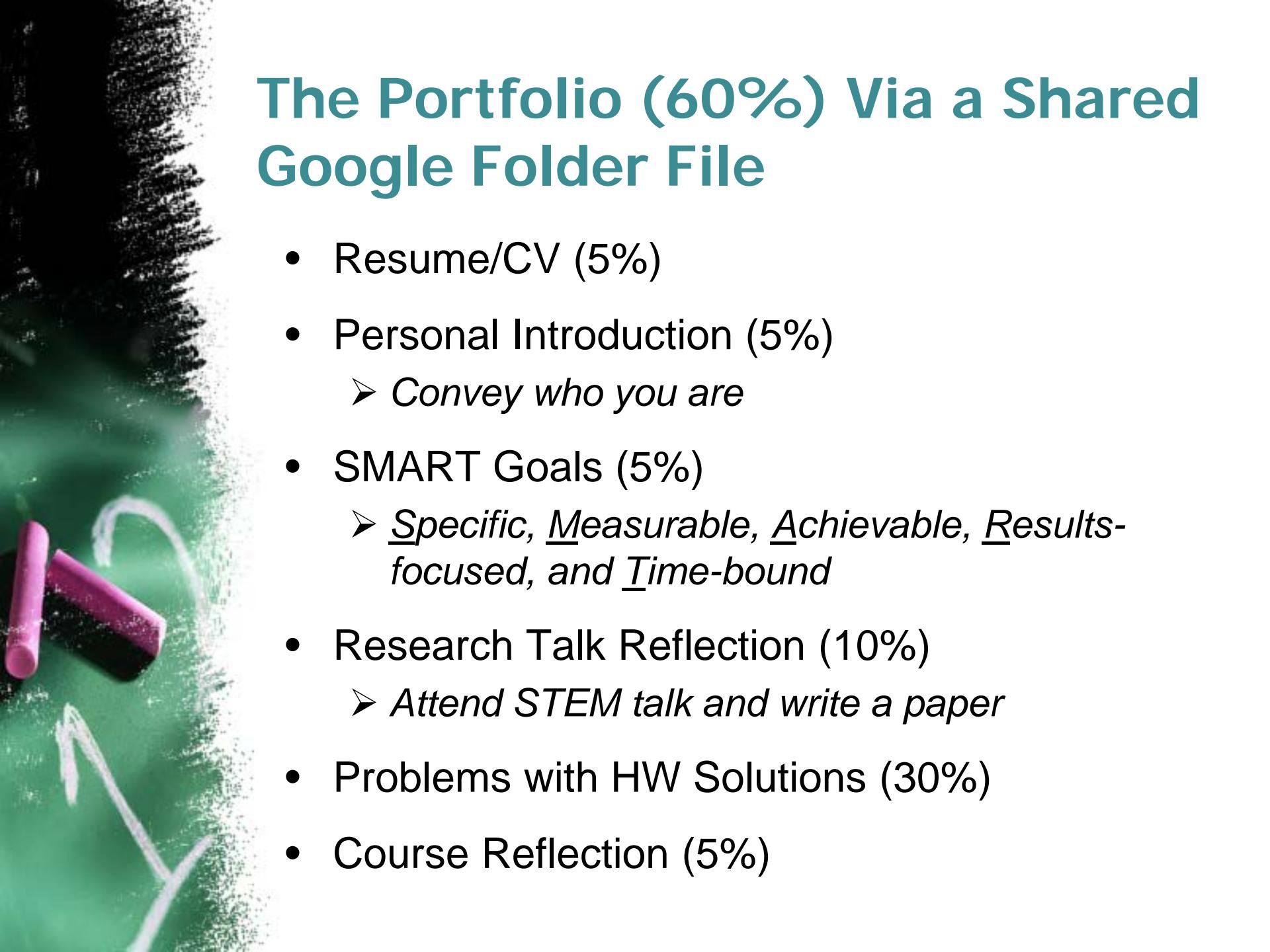
The Portfolio (60%) Via a Shared Google Folder File

- Resume/CV (5%)

- Personal Introduction (5%)
  - *Convey who you are*

- SMART Goals (5%)
  - *<u>S</u>pecific, <u>M</u>easurable, <u>A</u>chievable, <u>R</u>esults-focused, and <u>T</u>ime-bound*

- Research Talk Reflection (10%)
  - *Attend STEM talk and write a paper*

- Problems with HW Solutions (30%)

- Course Reflection (5%)

Section 2.2 Logically Equivalent Statements

Mathematical Reasoning Writing and Proof 2.0 by Sandstorm

Two expressions are **logically equivalent** provided that they have the same truth values for all possible situations. We write $P \equiv Q$.

Ex. Let's examine the conditional statement *"If you're an elephant, then you do not forget".*

   a. Circle the statement that is logically equivalent to the given statement.

- If you do not forget, then you are an elephant.

- If you do not forget, then you are not an elephant.

- If you are an elephant, then you forget.

- If you forget, then you are not an elephant.

   b. $P =$ $Q =$

   c. Translate the given statement into symbolic form.

   d. Translate your answer from part (a) into symbolic form.

   e. Construct a truth table to show that the statements in parts c and d are logically equivalent.
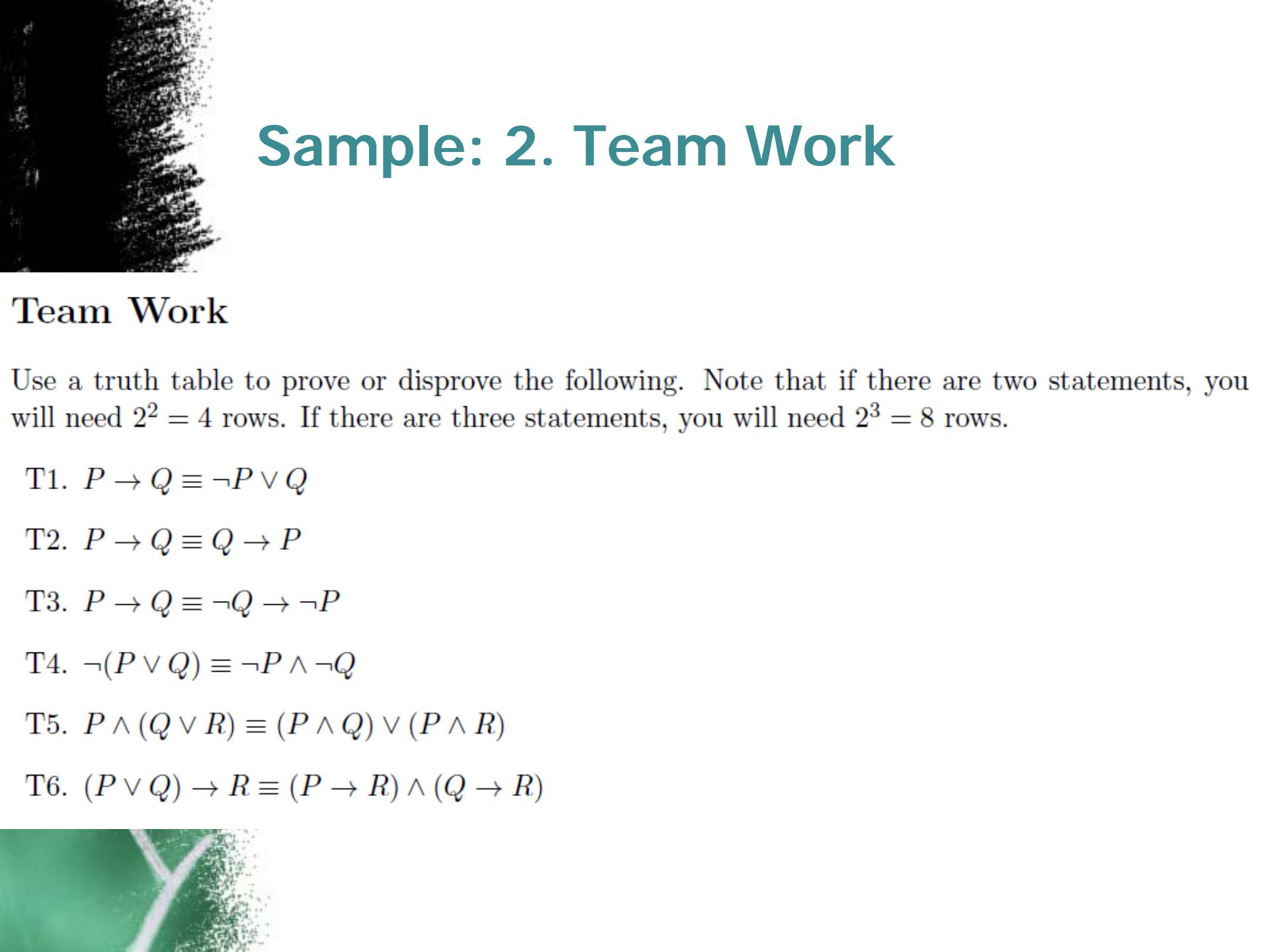
Sample: 2. Team Work

Team Work

Use a truth table to prove or disprove the following. Note that if there are two statements, you will need $2^2 = 4$ rows. If there are three statements, you will need $2^3 = 8$ rows.

T1. $P \rightarrow Q \equiv \neg P \vee Q$

T2. $P \rightarrow Q \equiv Q \rightarrow P$

T3. $P \rightarrow Q \equiv \neg Q \rightarrow \neg P$

T4. $\neg(P \vee Q) \equiv \neg P \wedge \neg Q$

T5. $P \wedge (Q \vee R) \equiv (P \wedge Q) \vee (P \wedge R)$

T6. $(P \vee Q) \rightarrow R \equiv (P \rightarrow R) \wedge (Q \rightarrow R)$
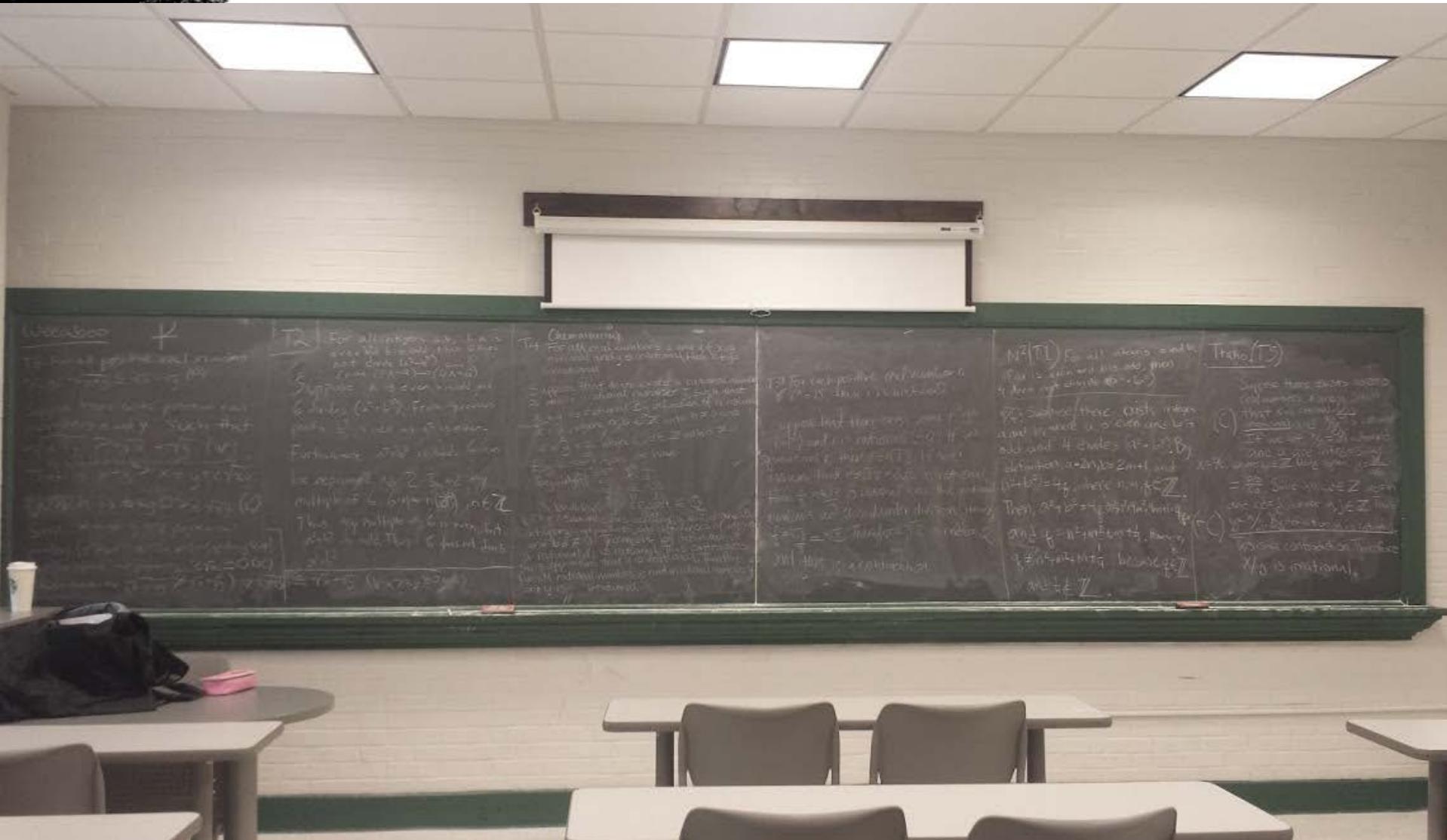
Sample: 4. Homework

Homework

✓ Read Section 2.3 Open Sentences and Sets

✓ Type up two <u>additional</u> problems using in LaTeX: one from section 2.1 and the other from section 2.2. Each problem should have:

— Why you choose the problem

— Statement of the problem and where it is posed in the textbook

— Complete Solution

The due date has been extended to Monday, September 14. Place the pdf and tex files in the shared Google Drive Folder file. Only files in this folder will be assessed. Note that for the HW Solutions portfolio component, the draft is 40% of the total grade and the final work is 60% of the total grade.

✓ A one page resume will be due in the shared Google Drive folder on Monday, September 21. This is the only document in this folder where typsetting in Microsoft Word is allowed.

Rubrics for Everything

Name: Rough Draft Rubric – HW #4

Criteria	Points Earned	Points Possible	Comments
Problem from section 3.1		3	State why you choose the problem
		3	Statement of problem and where it is posted in the textbook
		9	Complete solution
Problem from section 3.2		3	State why you choose the problem
		3	Statement of problem and where it is posted in the textbook
		9	Complete solution
LaTeX Compiles		5	PDF output has textbook appeal and template is used
Documents Placed in Google Drive		5	The tex file and pdf has been placed in the shared Google Drive folder
TOTAL		40	

A Hands-on Reading Course on Intro to Data Science

Introduction to Data Science with R/RStudio

- One math undergraduate and two atmospheric science graduate

- Met in my office once a week around a table

- Each student brought their own laptop

- Focused on programming and communication

- Began with Coursera's Data Science Specialization

  - *Outside of the meetings: Watch videos, complete specific modules*

  - *In the meetings: Discuss the modules and answer questions*

1. The Data Scientist's Toolbox

- Gained overview of data science

- Introduction to programming, GitHub, R and Rstudio

- Targeted for independent learning
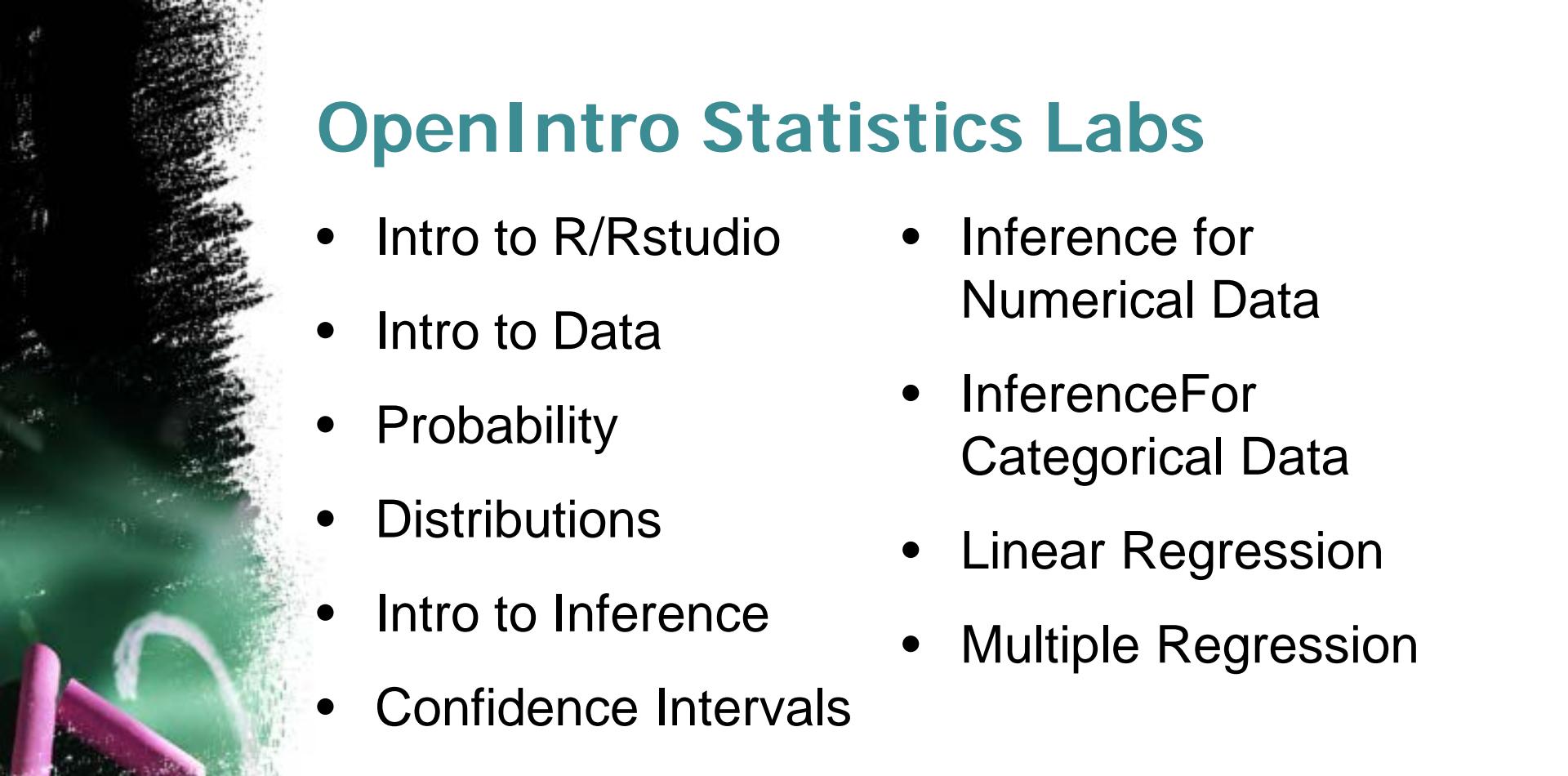
OpenIntro Statistics Labs

- Intro to R/Rstudio
- Intro to Data
- Probability
- Distributions
- Intro to Inference
- Confidence Intervals

- Inference for Numerical Data
- InferenceFor Categorical Data
- Linear Regression
- Multiple Regression

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Foundations for statistical inference - Sampling distributions

In this lab, we investigate the ways in which the statistics from a random sample of data can serve as point estimates for population parameters. We're interested in formulating a *sampling distribution* of our estimate in order to learn about the properties of the estimate, such as its distribution.

The data

We consider real estate data from the city of Ames, Iowa. The details of every real estate transaction in Ames is recorded by the City Assessor's office. Our particular focus for this lab will be all residential home sales in Ames between 2006 and 2010. This collection represents our population of interest. In this lab we would like to learn about these home sales by taking smaller samples from the full population. Let's load the data.

```
download.file("http://www.openintro.org/stat/data/ames.RData", destfile = "ames.RData")
load("ames.RData")
```

We see that there are quite a few variables in the data set, enough to do a very in-depth analysis. For this lab, we'll restrict our attention to just two of the variables: the above ground living area of the house in square feet (`Gr.Liv.Area`) and the sale price (`SalePrice`). To save some effort throughout the lab, create two variables with short names that represent these two variables.

```
area <- ames$Gr.Liv.Area
price <- ames$SalePrice
```

Let's look at the distribution of area in our population of home sales by calculating a few summary statistics and making a histogram.

```
summary(area)
hist(area)
```

Exercise 1   Describe this population distribution.

Machine Learning Mastery with Python Mini-Course

From Developer To Python Machine Learning Practitioner in 14 Days

Jason Brownlee

MACHINE LEARNING MASTERY

Lesson 1: Download and Install Python and SciPy Ecosystem

You cannot get started with machine learning in Python until you have access to the platform. Todays lesson is easy, you must download and install the Python 2.7 platform on your computer.

Visit the Python homepage[2] and download Python for your operating system (Linux, OS X or Windows). Install Python on your computer. You may need to use a platform specific package manager such as macports on OS X or yum on RedHat Linux.

You also need to install the SciPy platform[3] and the scikit-learn library. I recommend using the same approach that you used to install Python. You can install everything at once (much easier) with Anaconda[4]. Anaconda is recommended for beginners.

Start Python for the first time from command line by typing python at the command line. Check the versions of everything you are going to need using the code below:

```
1  # Python version
2  import sys
3  print('Python: {}'.format(sys.version))
4  # scipy
5  import scipy
6  print('scipy: {}'.format(scipy.__version__))
7  # numpy
8  import numpy
9  print('numpy: {}'.format(numpy.__version__))
10 # matplotlib
11 import matplotlib
12 print('matplotlib: {}'.format(matplotlib.__version__))
13 # pandas
14 import pandas
15 print('pandas: {}'.format(pandas.__version__))
16 # scikit-learn
17 import sklearn
18 print('sklearn: {}'.format(sklearn.__version__))
```

Listing 1: Print the versions of Python and the SciPy libraries.

If there are any errors, stop. Now is the time to fix them.

[2]https://www.python.org/
[3]http://scipy.org/
[4]https://www.continuum.io/downloads

Questions?

- "I've learned that you shouldn't go through life with a catcher's mitt on both hands; you need to be able to throw something back."

  ➢ *Maya Angelou*
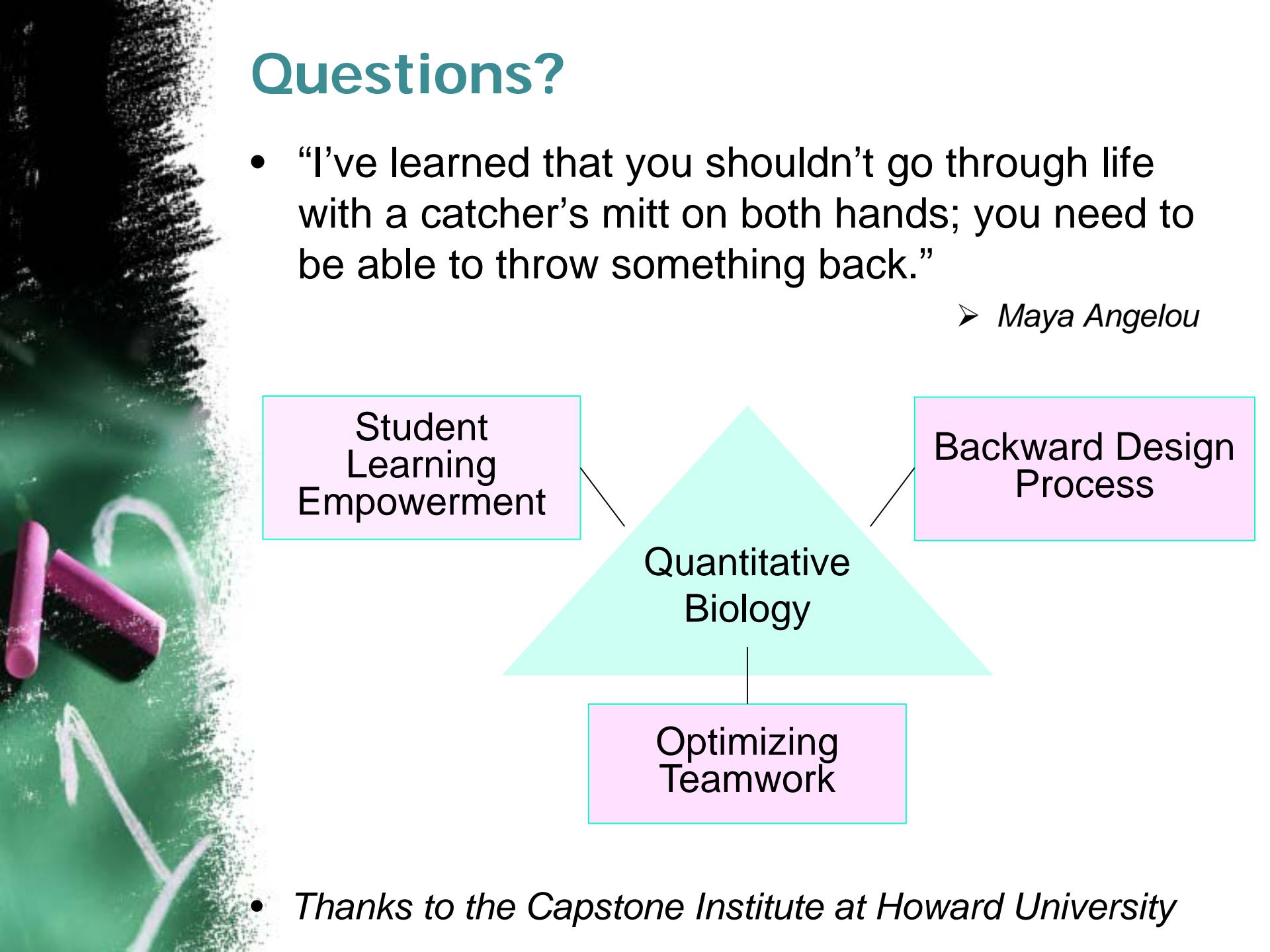
Student Learning Empowerment		Backward Design Process

Quantitative Biology

Optimizing Teamwork

- *Thanks to the Capstone Institute at Howard University*