JOINT MATHEMATICS MEETINGS
BALTIMORE • JAN 16–19, 2019
AMERICAN MATHEMATICAL SOCIETY
MATHEMATICAL ASSOCIATION OF AMERICA

Making it Happen: Modeling in Your Differential Equations Course

Audrey Malagon, Virginia Wesleyan University
Rachel Rossetti, Agnes Scott College
Brian Winkel, SIMIODE
Dina Yagodich, Frederick Community College

9:00 – 9:10 Welcome and Overview – Brian
9:10 – 9:30 Activity 1 – Dina (m&m)
9:30 – 9:50 Activity 2 – Rachel (Toss)
9:50 – 10:10 Activity 3 – Audrey (Kool Aid)
10:10 – 10:20 Wrap-Up and Sources – Brian

MAA
MATHEMATICAL ASSOCIATION OF AMERICA

www.simiode.org
SIMIODE
A SYSTEMIC INITIATIVE FOR MODELING INVESTIGATIONS & OPPORTUNITIES WITH DIFFERENTIAL EQUATIONS

Value of Modeling

Brian Winkel, Director of SIMIODE

Placing mathematics into the context of real world problems, makes the subject

- **meaningful,**
- **applicable,**
- **interesting, and**
- **powerful**

in the eyes of the students.

This aids with student attitudes about mathematics, resulting in increased

- **curiosity,**
- **persistence, and**
- **perceived usefulness.**

Moreover, such an approach can enhance **transferability** of the **mathematical knowledge** as it is based in a **reality with vivid imagery**.

Source: Silvia, P. J. 2008. Interest - the curious emotion. *Current Directions in Psychological Science*. 17(1): 57-60.

Distinguished Professor of History,
Charles G. Sellers (UC Berkeley):

"The notion that students must first be given facts and then at some distant time in the future will 'think' about them is both a cover-up and a perversion of pedagogy.

"One does not collect facts he does not need, hang on to them, **and then** stumble across the propitious moments to use them. One is **first** perplexed by a problem and then makes use of the facts to achieve a solution."

Source: Calder, L. 2006. Uncoverage: Toward a Signature Pedagogy for the History Survey. *The Journal of American History*. 92(4): 1358-1370.

According to the 2012 Report of the President’s Council of Advisors on Science and Technology, students cite **uninspiring introductory courses**, difficulty with the required mathematics, and an unwelcoming atmosphere as the three primary reasons for abandoning STEM fields.

Source: Presidents’ Council of Advisors on Science and Technology. 2012. *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*.

In their 2013 report, the National Research Council recommends that **college courses in the mathematical sciences draw connections between mathematics and other fields**, emphasizing that mathematical scientists must have knowledge beyond their own disciplines as well as an understanding of **how mathematics relates to other disciplines** such as science, engineering, medicine, and business.

Source: National Research Council. 2013. *The Mathematical Sciences in 2025.* The National Academies Press: Washington, DC.

“Another well-entrenched tenet of traditional instruction is the notion that students must first master the underlying principles and theories of a discipline before being asked to solve substantive problems in that discipline.

“An analysis of the literature suggests that there are sometimes good reasons to `teach backwards’ by **introducing students to complex and realistic problems before exposing them to the relevant theory and equations.”**

Source: Prince, M. J. 2007. The case for inductive teaching. ASEE *PRISM*. October: 55.

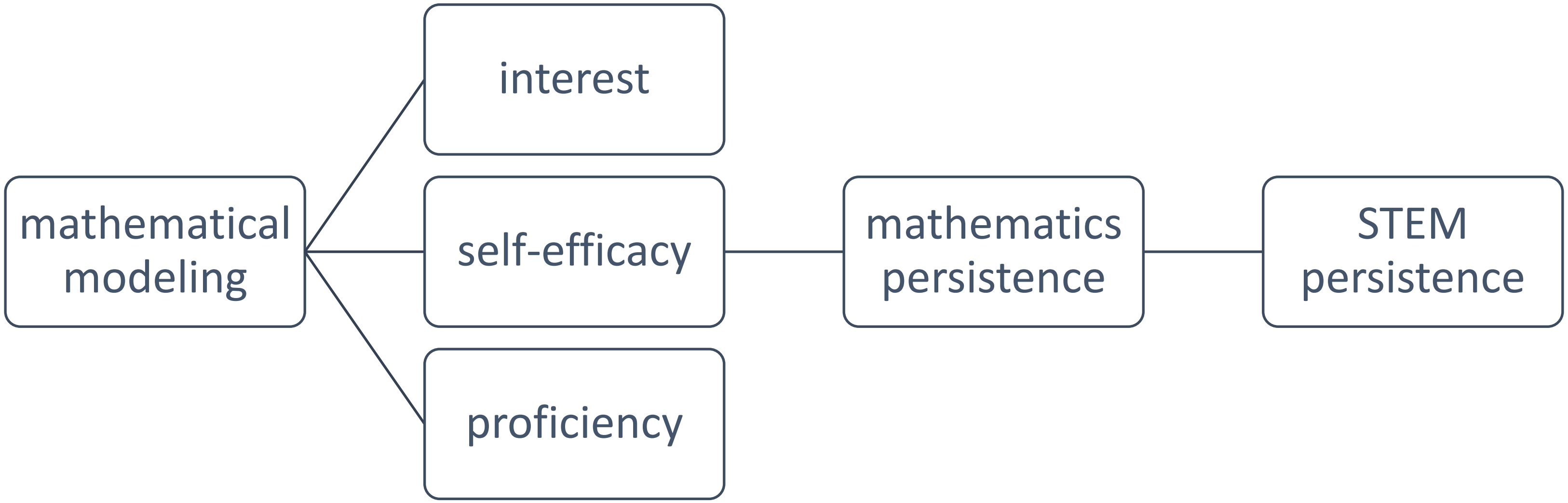
We define a **modeling-first approach** as one that uses real data for phenomena to motivate the creation of a mathematical model; to foster discovery of the techniques used to solve the mathematical problem; and to drive discussions about the meaning of the solution.

- Students are **presented with a question** related to an outcome or a phenomenon to be understood. Ideally, there is a stakeholder with interest in the answer.
- Students are either given data or instructions to run experiments and **collect data**.
- In groups or as a class, **students develop a differential equations mathematical model**.
- Students are motivated to **solve the differential equations** because they want to answer the originating question.
- Solution in hand, **students reflect on their answer,** asking the following questions: Does it make sense? Does the solution capture the key phenomenon driving the physical situation being modeled? Does the model need to be modified? What is the long-term behavior of the system? Was it possible to answer the stakeholder's question?
- Students are encouraged to **generalize with more questions**: Does solution always behave like this? What about similar systems? Does a small change in the parameters cause a change in output? What happens if initial conditions change? Is there/what is the "tipping" point? What other useful information can be provided to the stakeholder?

In the 2015 MAA publication, *CUPM Curriculum Guide: Course Reports Differential Equations,* there is **strong support for including modeling and technology in differential equations courses**.

Further, from the same CUPM report, under Technology and the Mathematics Curriculum, there is **strong encouragement for the values from technology** in many aspects of coursework: exploration, computation, communication, assessment, and motivation.

Source: Committee on the Undergraduate Program in Mathematics. 2015. *CUPM Curriculum Guide. Course Reports. Differential Equations*. Washington DC: MAA.



Source: Czocher, J. 2018. Report on Assessment/Evaluation for SIMIODE's SCUDEM II and III 2018.

Consider the placement of modeling in a differential equations course.

This pivotal STEM course is one in which applications are its *raison d'être* .

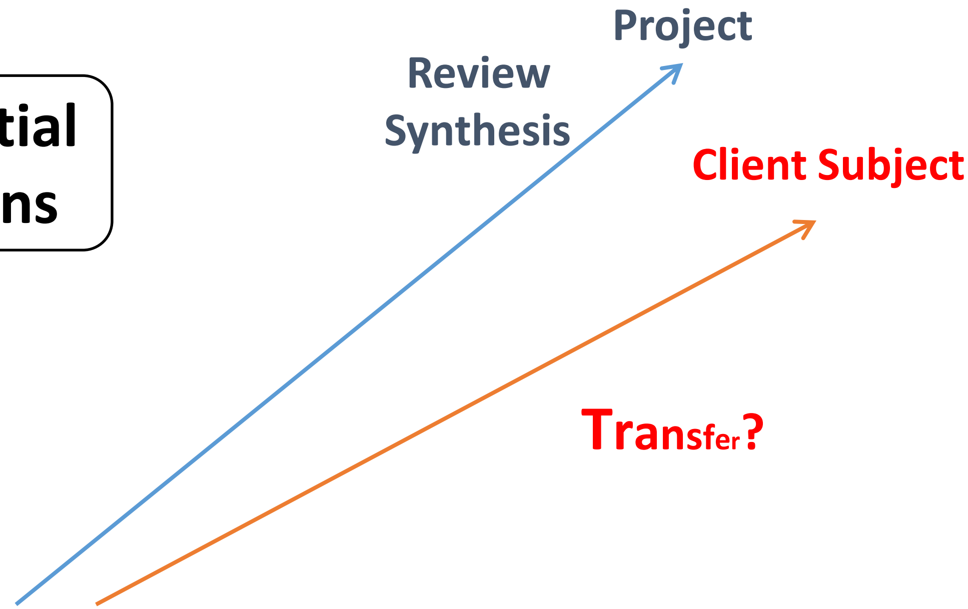
Differential Equations

Client Subject

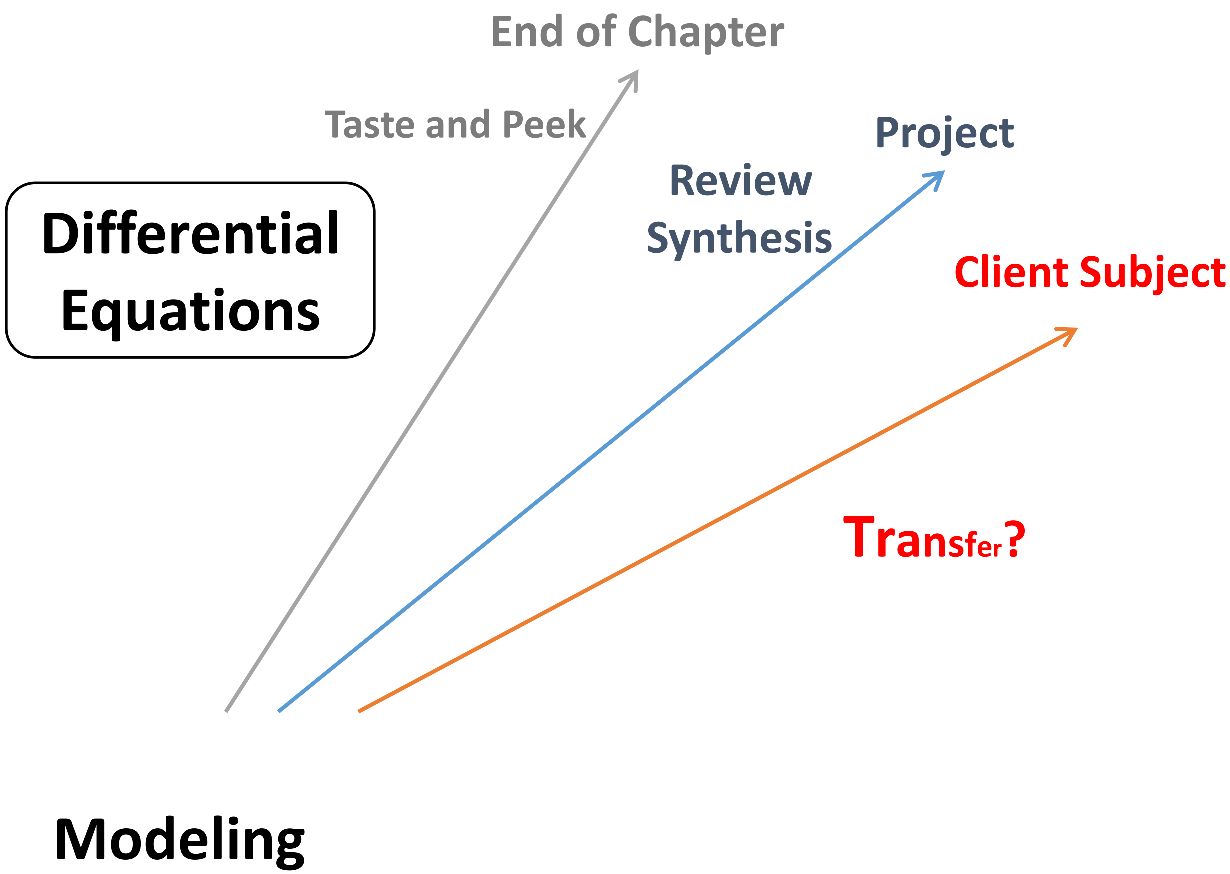
Transfer?

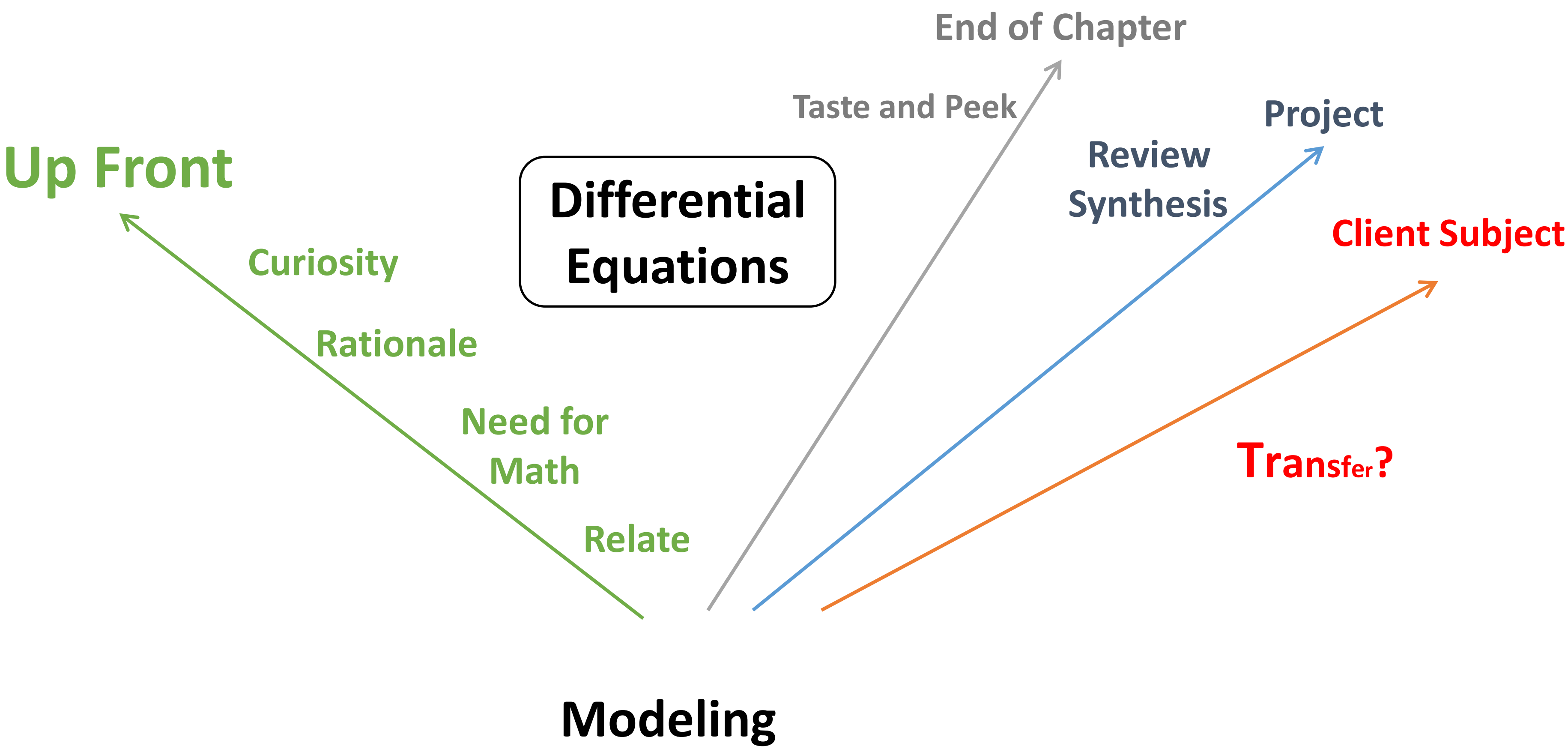
Modeling

Differential Equations



Modeling


End of Chapter
Taste and Peek
Project
Review
Synthesis
Differential
Equations
Client Subject
Transfer?
Modeling


End of Chapter
Taste and Peek
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Up Front
Differential
Equations
Client Subject
Curiosity
Rationale
Need for
Math
Transfer?
Relate
Modeling

Fun with M&Ms

Population Modeling as Introduction to Differential Equations

Dina Yagodich
Frederick Community College

First Day of Class – Start with Modeling!

Why modeling the first day of class?

- Sets up expectations for the semester (better than just reading the syllabus)
- Simple activity to introduce concept of modeling
- Introduces top terms in first day by experiencing instead of just reading
- Who doesn't like M&Ms?

Resources available at

Brian Winkel (2015), "1-001-S-MandMDeathAndImmigration," https://www.simiode.org/resources/132.

Materials

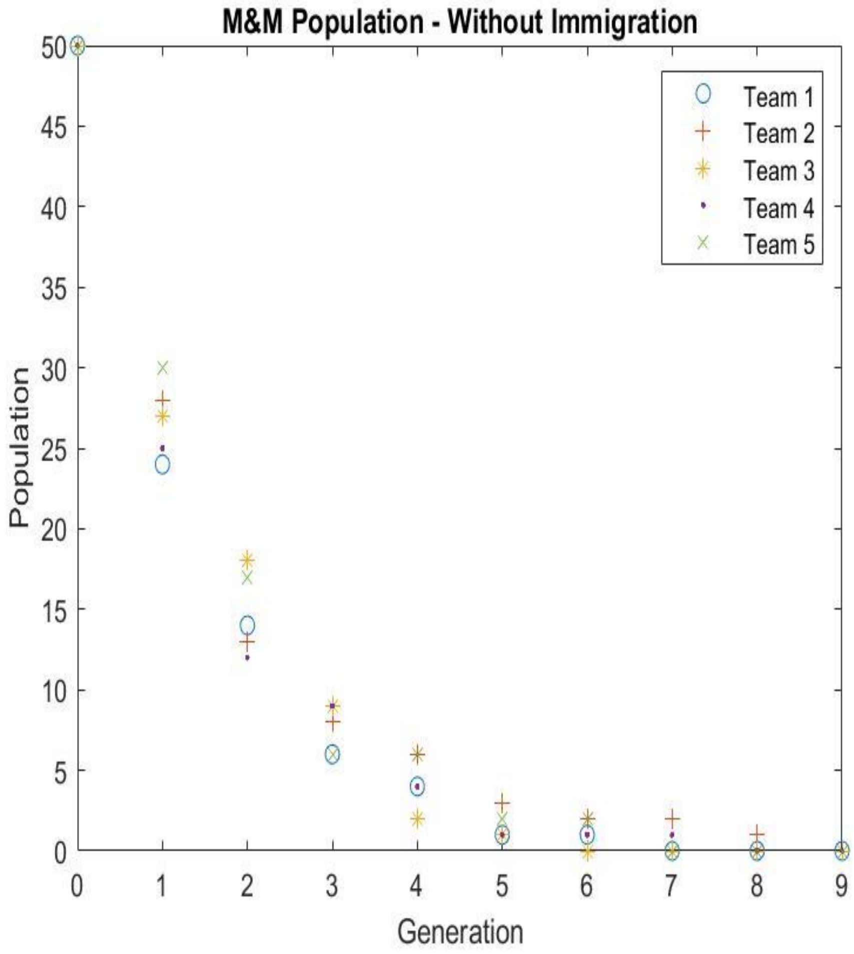
- Bag of M&Ms (Costco now sells big tubs)
- Two cups per team – one labeled with an X, one filled with 50 candies
- MATLAB (or similar software)
- Handout to record data per team
- Modeling project directions (to be done outside of class by students)

Population Modeling – Without Immigration

Read the directions and – before you begin – give guesses on number of "live" M&Ms at the end of the experiment and how many generations it will take to get to this number.

1. Toss M&Ms gently on the table.
2. Remove the M&Ms with the 'm' facing up – they "die". Place in 'X' cup.
3. Count the number of M&Ms remaining. Record the data.
4. Repeat until you are satisfied that you have reached the final number.

Results from Six Teams – using MATLAB



Used coin flips from random.org

MATLAB code:

```
x=0:9;
y1=[50 24 14 6 4 1 1 0 0 0];
y2=[50 28 13 8 6 3 2 2 1 0];
y3=[50 27 18 9 2 1 0 0 0 0];
y4=[50 25 12 9 4 1 1 1 0 0];
y5=[50 30 17 6 6 2 2 0 0 0];
plot(x,y1,'o')
hold on
plot(x,y2,'+')
plot(x,y3,'*')
plot(x,y4,'.')
plot(x,y5,'x')
hold off
```

A bit of “lecture”

- How population changes over time – change of rate…
  What does that remind you of?
- The “final” number – steady state solution / equilibrium solution
- The “getting to the final number” numbers – transient solution
- What type of curve does the data seem to form? (e is everywhere…)
- Discrete vs continuous data
- Create difference equation
- Form differential equation – Solve in MATLAB
- To find constant *c* – need how many M&Ms you started with (Initial Condition)

ON TO IMMIGRATION!

Population Modeling – With Immigration

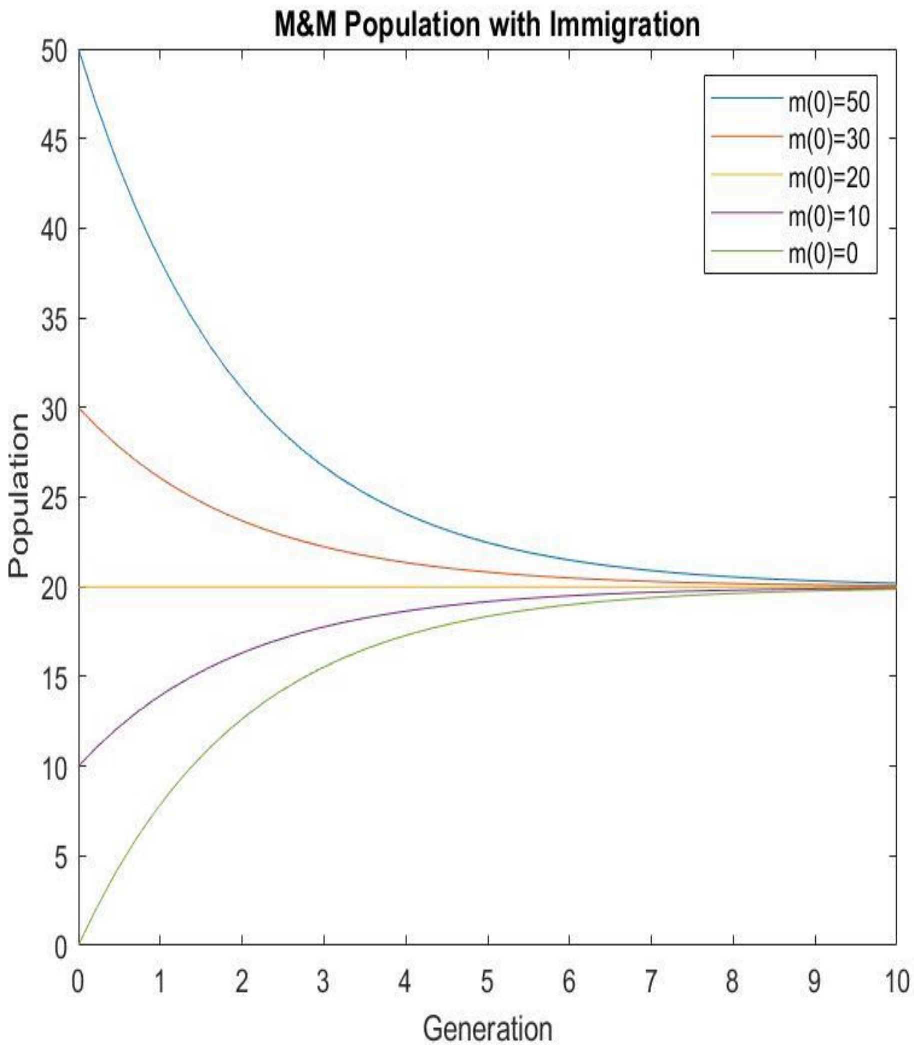
Read the directions and – before you begin – give guesses on number of "live" M&Ms at the end of the experiment and how many generations it will take to get to this number. NOTE: Group start with a different number of M&Ms.

1. Toss M&Ms gently on the table.
2. Remove the M&Ms with the 'm' facing up – they "die". Place in 'X' cup.
3. Add 10 new immigrant M&Ms (can use from 'X' cup)
4. Count the number of M&Ms remaining. Record the data.
5. Repeat until you are satisfied that you have reached the final number.

A bit of "lecture"

- Were you surprised by steady state solution?
- Create difference equation
- Form differential equation – Solve in MATLAB
- Without immigration – separable differential equation
- With immigration – linear differential equation
- Integration constant – no longer moving graph up/down like Calc II – creates family of curves

After Solving in MATLAB

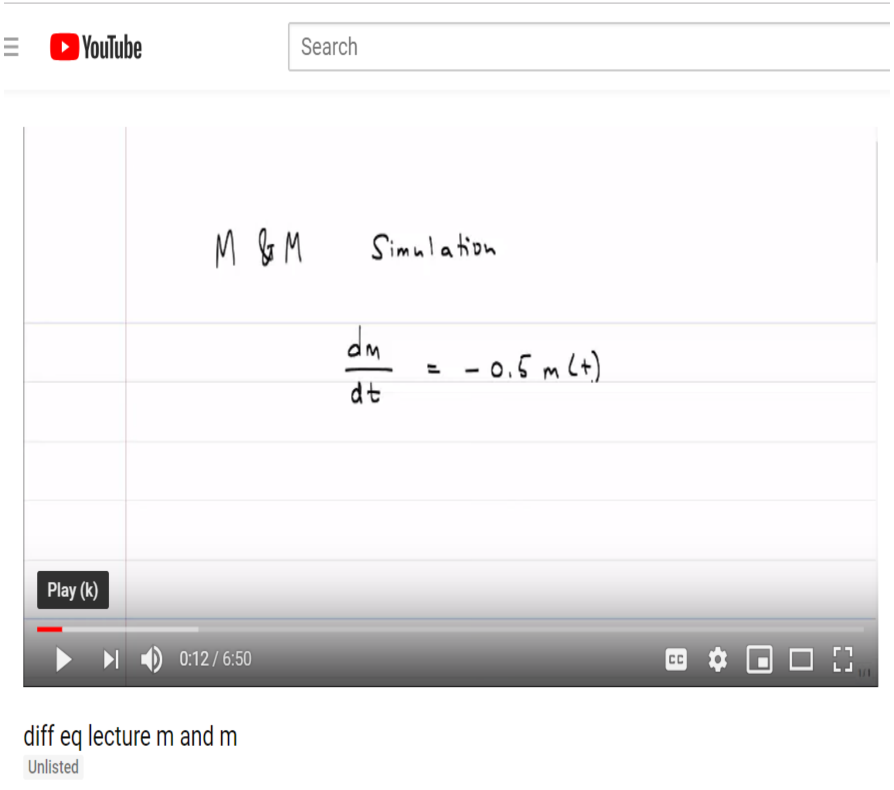


MATLAB Code:

```
a1=dsolve('Dy=-
0.5*y+10','y(0)=50')
a2=dsolve('Dy=-
0.5*y+10','y(0)=30')
a3=dsolve('Dy=-
0.5*y+10','y(0)=20')
a4=dsolve('Dy=-
0.5*y+10','y(0)=10')
a5=dsolve('Dy=-
0.5*y+10','y(0)=0')
fplot(a1,[0 10])
hold on
fplot(a2,[0 10])
fplot(a3,[0 10])
fplot(a4,[0 10])
fplot(a5,[0 10])
```

Simple Enough for Online Class

- Give students similar worksheet (they must supply the M&Ms)
- After students submit their work, I send them an unlisted YouTube video similar to what is taught in class.
- https://youtu.be/Ji8a_Elkj08



Dice Tossing

Exponential Decay with Dice

Rachel Rossetti
Agnes Scott College

Dice Tossing - Outline

1. Overview (2 min)

2. Data Collection (6 min)

3. Modeling (8 min)

4. Discussion and Variations (4 min)

Resources available at

Brian Winkel (2015), "1-002-T-Tossing," https://www.simiode.org/resources/7

Dice Tossing - Overview (2 min)

- Introduces exponential decay
- 1st week of class
- In class activity (can be used outside of class)
- Students practice computing sum of square error and curve fitting (optional)

Set up & Materials

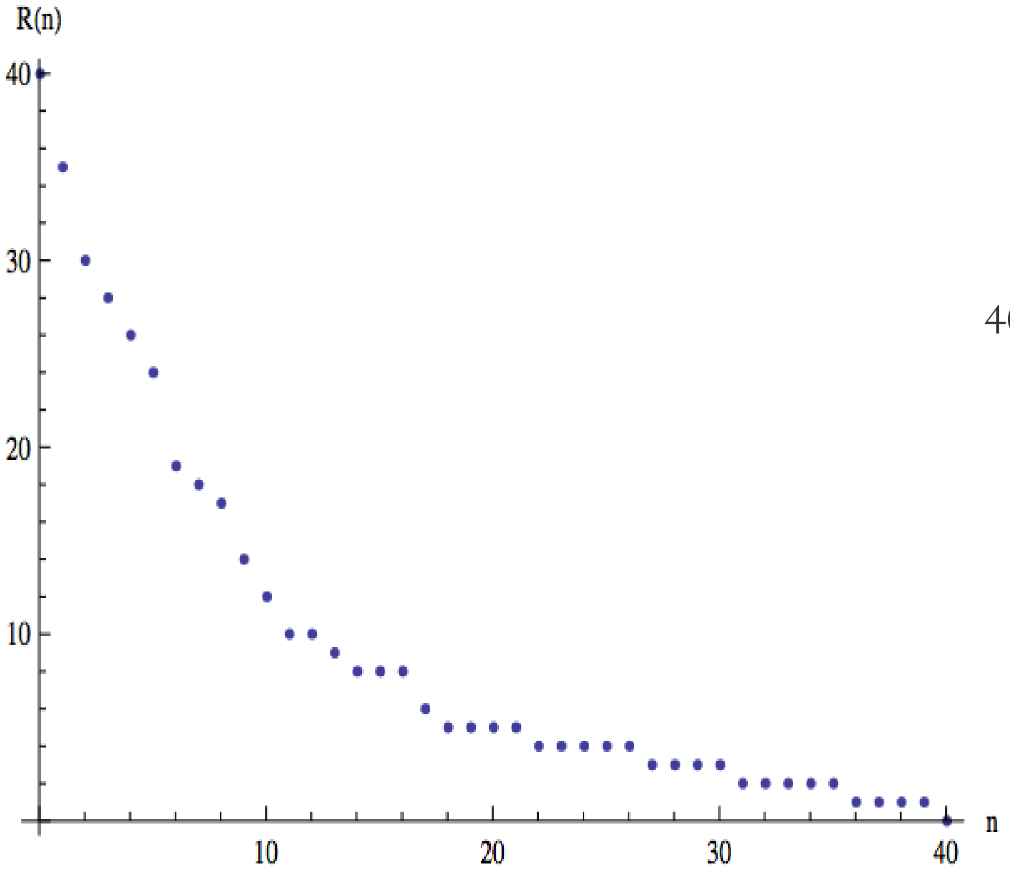
- Groups of 25-40 ten-sided dice ***OR*** simulated data from SIMIODE.org
- Software like Mathematica, Maple, etc. (optional)

Dice Tossing - Data Collection (6 min)

You have a set of 30 dice at your table. Working in groups, roll the dice. Remove all dice that land showing a 1 on top. Record the number of dice remaining. Repeat until no dice remain.

Plot your data and discuss the questions from the worksheet.

Dice Tossing - Data Collection (6 min)



Simulated data using
40 dice available at SIMIODE.org

Brian Winkel (2015), "1-002-T-Tossing," https://www.simiode.org/resources/7

Dice Tossing - Modeling (8 min)

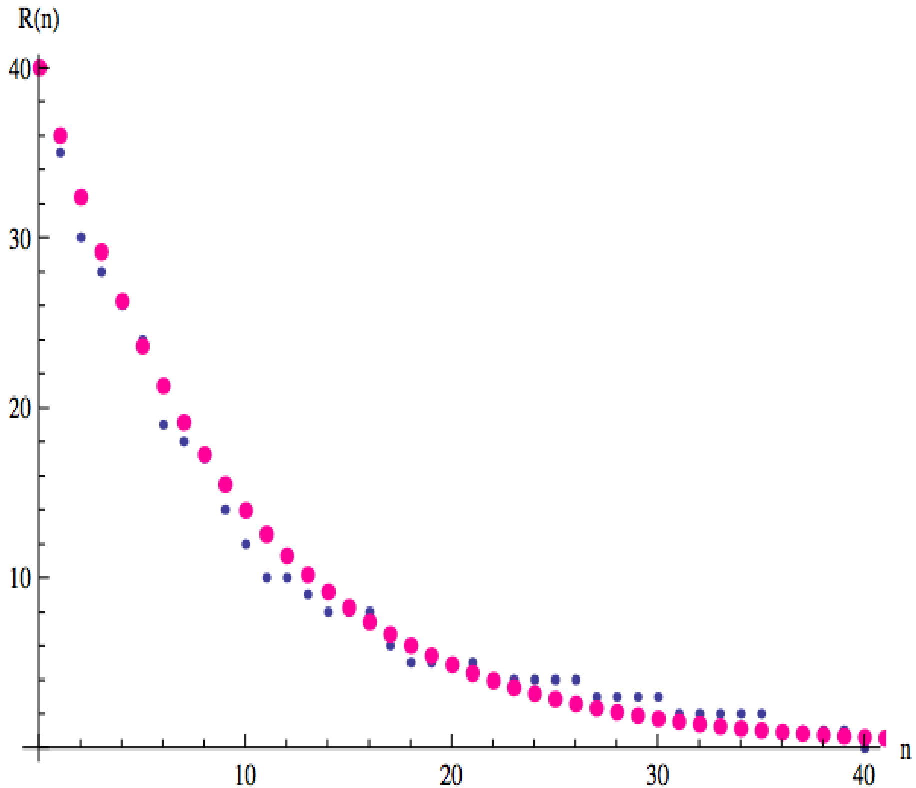
1. Build a model for R(n), the number of dice remaining after n tosses.

2. Use a difference equation to model R(n), the number of dice remaining after n tosses.

3. Use a differential equation to model R(t), the number of dice remaining after t tosses, where we make a toss every minute.

Dice Tossing - Discussion and Variations (4 min)

1. Build a model for R(n), the number of dice remaining after n tosses.



Brian Winkel (2015), "1-002-T-Tossing," https://www.simiode.org/resources/7

Assumptions

- Each die is fair
- Each die acts independently

Model

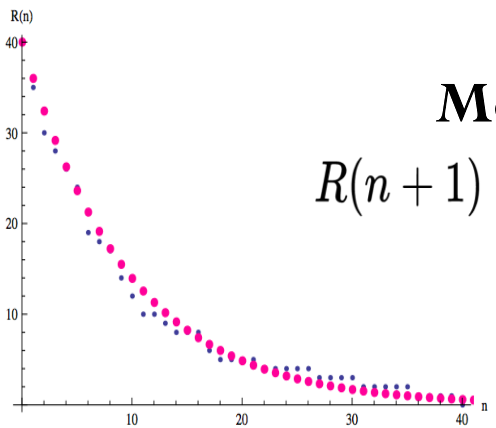
$$R(n) = R(0)(.9)^n$$

Error

$$SSE(.9) = \sum_{i=0}^{N} (\hat{R}_i - R(0)(.9)^i)$$

Dice Tossing - Discussion and Variations (4 min)

2. Use a difference equation to model R(n).



Model

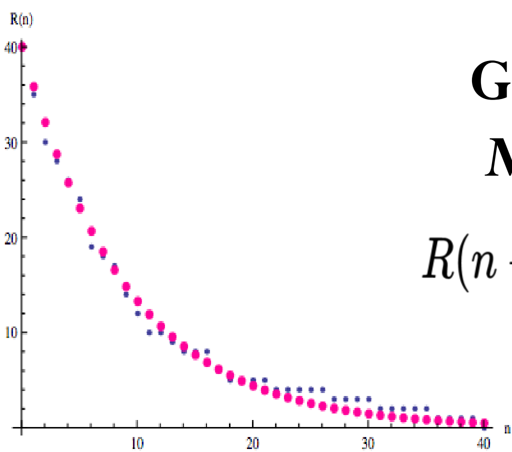
$$R(n+1) = (.9)R(n)$$

Solution

$$R(n) = R(0)(.9)^n$$

Error

$$SSE(.9) = \sum_{i=0}^{N}(\hat{R}_i - R(0)(.9)^i)$$



General Model

$$R(n+1) = kR(n)$$

Solution

$$R(n) = R(0)k^n$$

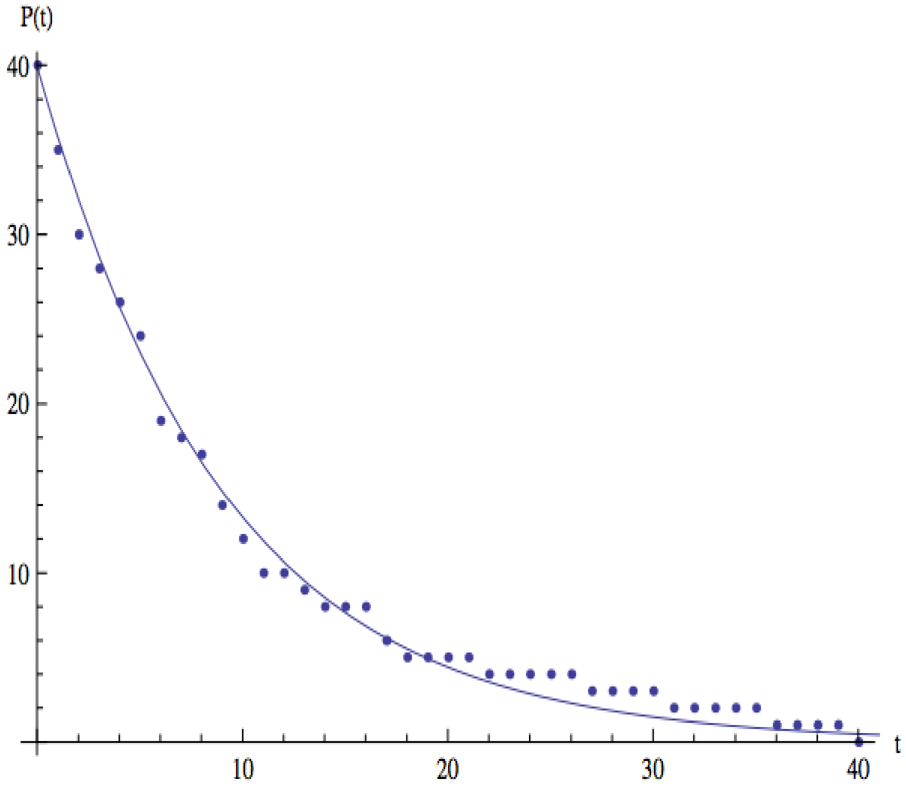
Error

$$SSE(k) = \sum_{i=0}^{N}(\hat{R}_i - R(0)k^i)$$

Brian Winkel (2015), "1-002-T-Tossing," https://www.simiode.org/resources/7

Dice Tossing - Discussion and Variations (4 min)

3. Use a differential equation to model R(t).



Brian Winkel (2015), "1-002-T-Tossing," https://www.simiode.org/resources/7

Assumptions

- Each die is fair
- Each die acts independently
- We approximate the change in one unit of time with the instantaneous rate of change at that time.

Model

$$R'(t) = -.1R(t) \quad \text{or} \quad R'(t) = -cR(t)$$

Solution

$$R(t) = R(0)e^{-ct}$$

Use Mathematica `FindFit` command to fit a curve with least square error.

Don’t Drink the Kool-Aid

Audrey Malagon, Virginia Wesleyan University

- Mixing activity
- Introduces Linear DE
- First Lab, 2nd week of class
- Students have seen separation of variables, slope fields, and Euler’s method

Scenario 1: Drink Mix Flows In

- Initial conditions and predictions
  - Receiving tank initial volume: 3.8 L of plain water
  - Top tank initial concentration: 8.56g/L
  - Flow rate: 1.2 L/minute
  - Spout on receiving tank is closed.

Predict what will happen to the amount of drink mix $A(t)$ in the receiving tank as top tank flows into bottom with bottom spout *closed*. How much drink mix will be in bottom tank at the end of the experiment? When the top tank is only half full?

Set Up and Materials

- Clear drink containers with spouts (party supply store). Measure and mark each liter on outside.
- Powdered drink mix in bright color
- 2 Buckets – one to catch, one to elevate
- Stirring sticks
- Stopwatch or timer app
- Scales to measure grams of drink mix

OR

- Videos and Data Sheets

Scenario 1: Observe and Record

Create a Model

- Create a differential equation model for the amount $A(t)$ of drink mix at time t and verify that model predicts correct concentration of drink mix at known data points.

Results

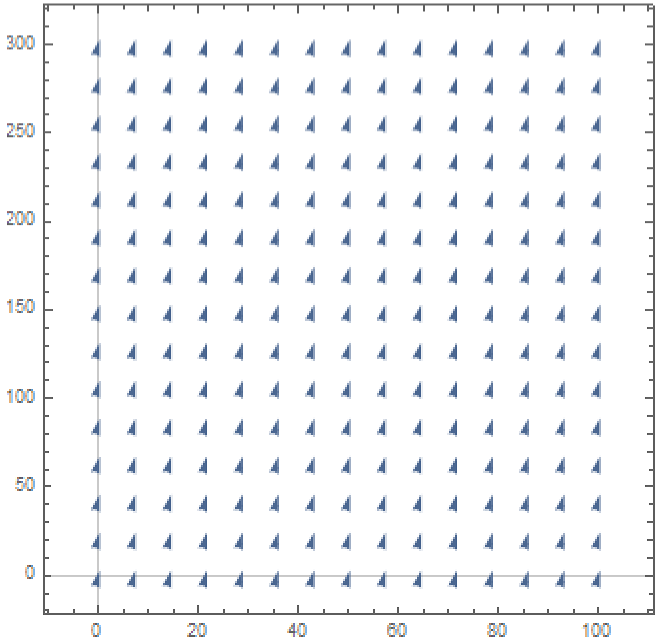
The results here are based on the experimental data provided below.

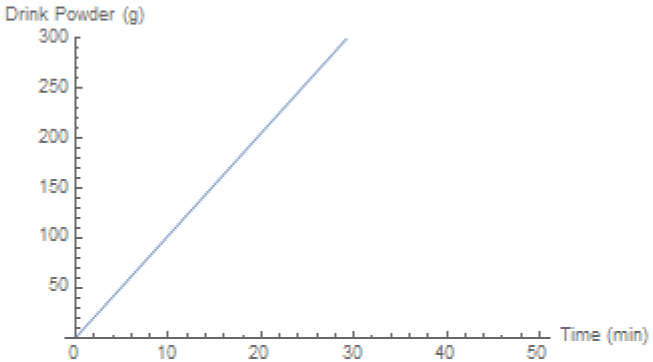
Concentration of top tank: 8.56 g/L
Flow rate for both tanks: 1.2 L/min
Initial volume of bottom tank for Scenario 1: 3.8 L
Initial volume of bottom tank for Scenario 2: 7.6 L

Scenario 1

$\frac{dA}{dT} = 10.27$, A(0)=0

```
VectorPlot[{1, 10.27}, {x, 0, 100}, {y, 0, 300}, VectorScale → {.02, Automatic, None}, GridLines → {{0}, {0}}]
```





Scenario 2: Drink Mix Flows In and Out

- Initial conditions and predictions
  - Receiving tank initial volume: 7.6 L of plain water
  - Top tank initial concentration: 8.56g/L
  - Flow rate: 1.2 L/minute from each tank.
  - Spout on receiving tank is open.

Predict what will happen to the amount of drink mix *A(t)* as top tank flows into bottom with bottom spout *open*. How much drink mix will be in bottom tank at the end of the experiment? Will it change color like before? Will it be the same color as top tank?

Sketch a *prediction* graph of amount of drink mix in bottom tank as a function of time *t*.

Scenario 2: Observe and Record

Create a Model

- Create a differential equation model for the amount $A(t)$ of drink mix at time t and verify that model predicts correct concentration of drink mix at known data points.

Results

The results here are based on the experimental data provided below.

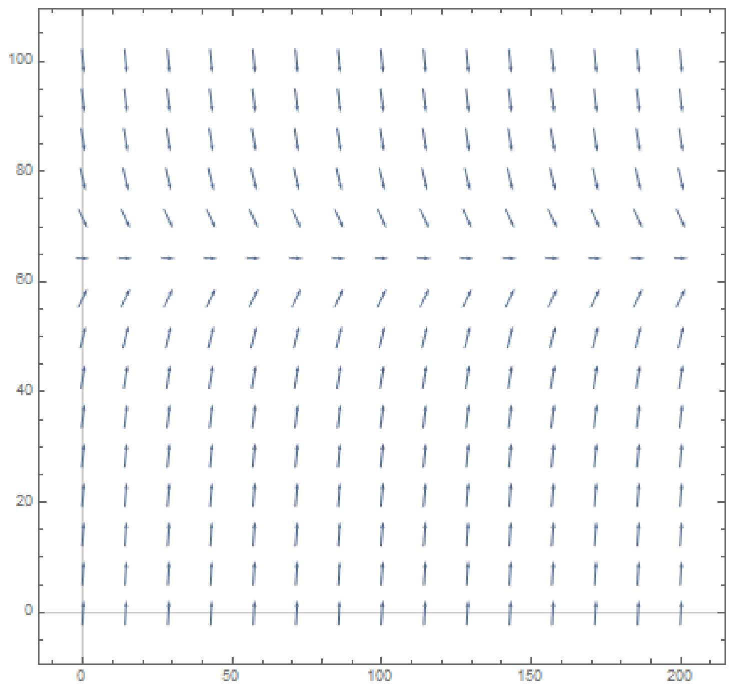
- Concentration of top tank: 8.56 g/L
- Flow rate for both tanks: 1.2 L/min
- Initial volume of bottom tank for Scenario 1: 3.8 L
- Initial volume of bottom tank for Scenario 2: 7.6 L

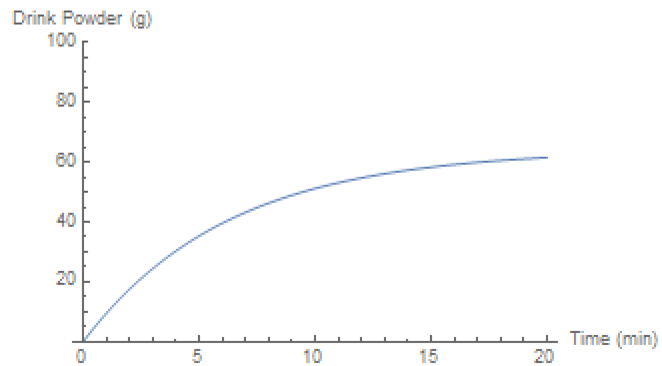
<u>Scenario 2</u>

$\frac{dA}{dt} = 10.27 - .16\,A$, A(0)=0

Note that this equation is autonomous, so a critical point can be found at A=64.2. This is also shown in the direction field.

```
VectorPlot[{1, 10.27 - .16 y}, {x, 0, 200}, {y, 0, 100}, VectorScale → {.02, Automatic, None}, GridLines → {{0}, {0}}]
```





Restrictions on *t*?

SIMIODE

501(c)3 Non-Profit Organization

Funded by the National Science Foundation

- **SIMIODE** offers materials and support for faculty who want to use modeling to motivate and teach differential equations.

- Everything in **SIMIODE** is FREE and all materials are offered according to a Creative Commons license.

Modeling Scenarios
The Heart of SIMIODE

- Scenario Attributes
  - **Searchable**: keywords
  - **Sortable topics**: separable equations, logistic growth, pde, parameter estimation, linear, etc.
  - **Sortable themes**: physics, biology, disease, energy, economics, engineering, etc.
  - **Structures**: guided step-by-step, exploration, open-ended
  - **Formats**: in-class activity, out-of-class project, simulation, short exercise

Scenarios for in-class groups or discussion

Title	1-032-T-WordPropagation	1-079-T-HomeHeating	1-41-T-AirToTop
Author(s)	Rachel L. Bayless Rachelle C. DeCoste	Kurt Bryan	John Sieben
Problem	Modeling the rate at which the word jumbo has propagated through English language texts over time.	Model the heating of a house while away on vacation.	Examine ascent rates and air needed for divers to safely return to surface from various depths.
Highlights	• Exponential growth. • Introduction to differential equations for first day of class. • Data retrieved from Google Ngram. • Propagation of other words display different behavior (groovy, ration).	• Newton's Law of Cooling, linear (nonhomogeneous) ode. • Inclusion of a time-dependent heat source term to Newton's Law of Cooling. • Task sequence of 11 exercises for students to complete.	• Linear, separable ode. • Guided discussion with some fill-in-the-blank questions.

Scenarios requiring multiple class periods and/or out of class project

Title	1-038-T-Ebola	1-024-T-MalariaControl	1-021-T-FeralCatControl
Author(s)	Lisa Driskell	MAJ Davis Culver	Rachel L. Bayless Nathan Pennington
Problem	Model the spread of Ebola in the 2014 outbreak in West Africa.	Analyze malaria preventative measures for soldiers deployed to West Africa to aid in the Ebola outbreak of 2014.	Model the implementation of various control methods for town's feral cat problem.
Highlights	• Exponential and logistic growth. • Sequence of guiding questions for quantitative and qualitative analysis. • Full set of outbreak data collected bi-weekly and published by WHO is available • Model fits well to real data.	• Exponential and logistic growth (decay), numerical methods. • Considers both preventative drug concentration in bloodstream and mosquito population control • Technology used/needed.	• Modified exponential growth. • Project posed as a letter from a client company with scenarios including no control and trap-neuter-return. • Open project with few guiding hints. • Introduction to using differential equations for modeling. • Suggestions for future study and student projects.

Scenarios for short in-class examples or exercises

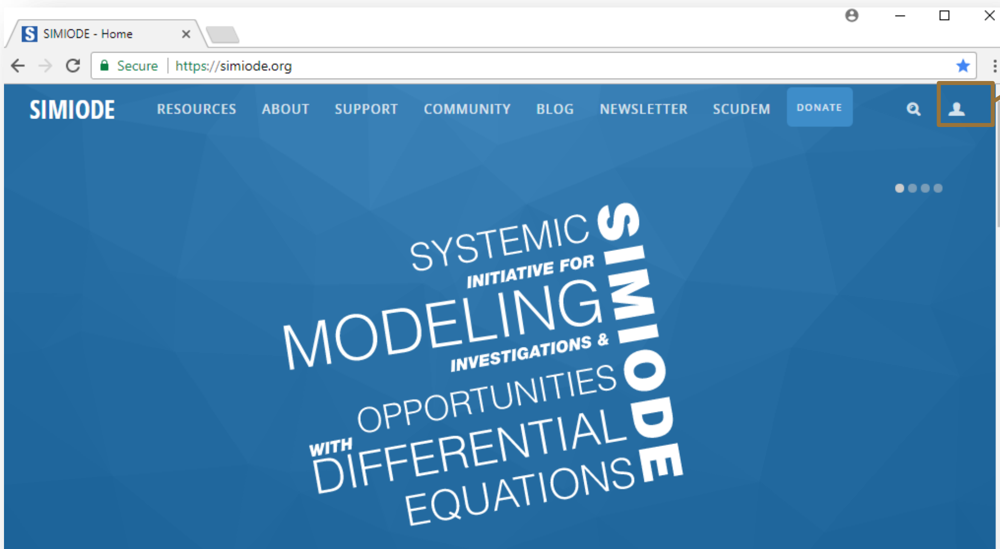
Title	5-030-T-AirshedSulphur	1-086-T-MedicinalPill
Author(s)	Brian Winkel	Brian Winkel
Problem	Analyze model of air pollutants due to inversion in mountain valleys.	Model amount of drug in bloodstream when administered only once and when administered on a regular schedule.
Highlights	• Linear system • Vary parameters and qualitative analysis about long term behavior.	• Compartment model. • Mathematica file and a pdf version of the file available in supporting documents.

Scenarios involving a simulation or lab component

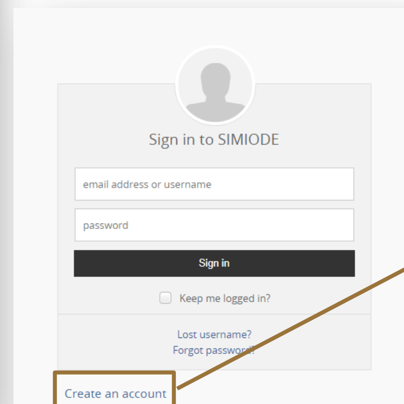
Title	1-037-T-CommonColdSpread	1-042-T-Kool-Aid
Author(s)	Richard Corban Harwood	Kristin Burney, Lydia Kennedy, Audrey Malagon
Problem	Simulate and model the spread of a common cold throughout the university residence hall.	Observe and model the change in concentration of powder drink mix as water flows through tanks.
Highlights	• Separation of variables, slope field, parameter estimation, optimization, etc. • Simulation using beans and residence hall floor plans (customizable) • Introduces several course topics over course of two weeks. • One-day abridged version also described	• First-order linear and separable • Hands-on lab experiment to observe Kool-Aid mixing in tanks • Model verification with experimental observations.

SIMIODE.org

Creating an account and logging in



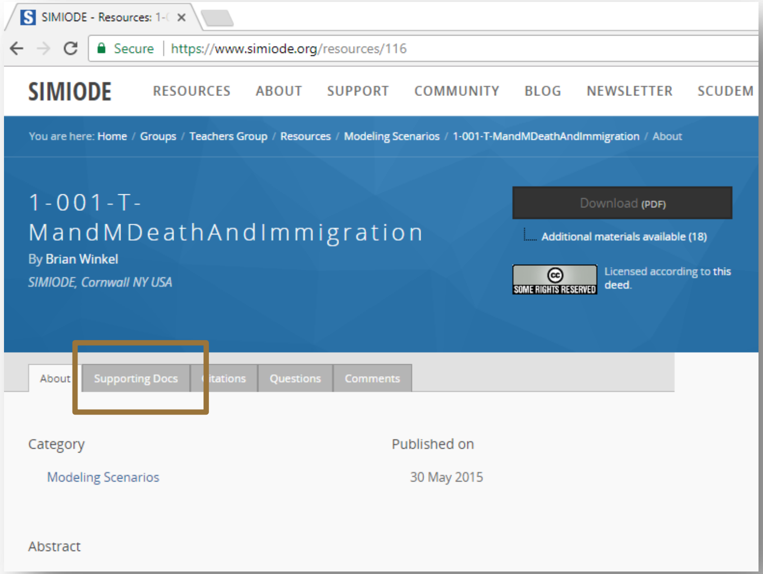
Click icon to login



Create an account

Accessing Modeling Scenarios

- Create an account
  - Note: Your account and teacher status must be approved by an administrator before gaining access to Teacher Versions and Supporting Docs.
- Choose a Modeling Scenario
  - Resources -> Modeling Scenarios
  - Select the Teacher Version of chosen scenario
  - Click Supporting Docs tab to access all documents related to the scenario

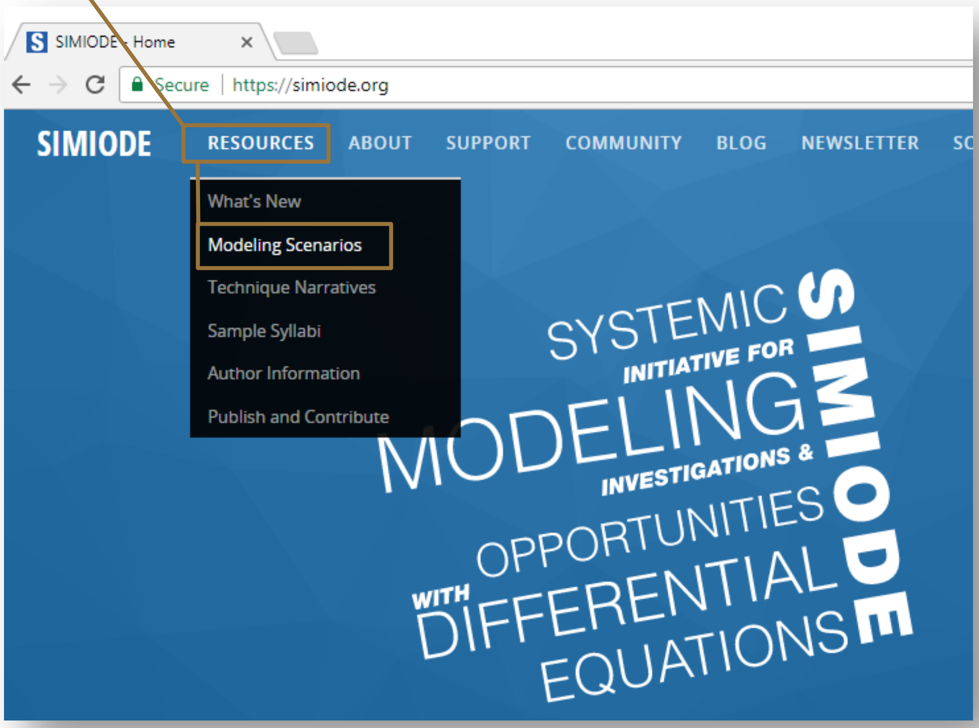


Wifi Network: JMM 2019
Password: ****

SIMIODE.org

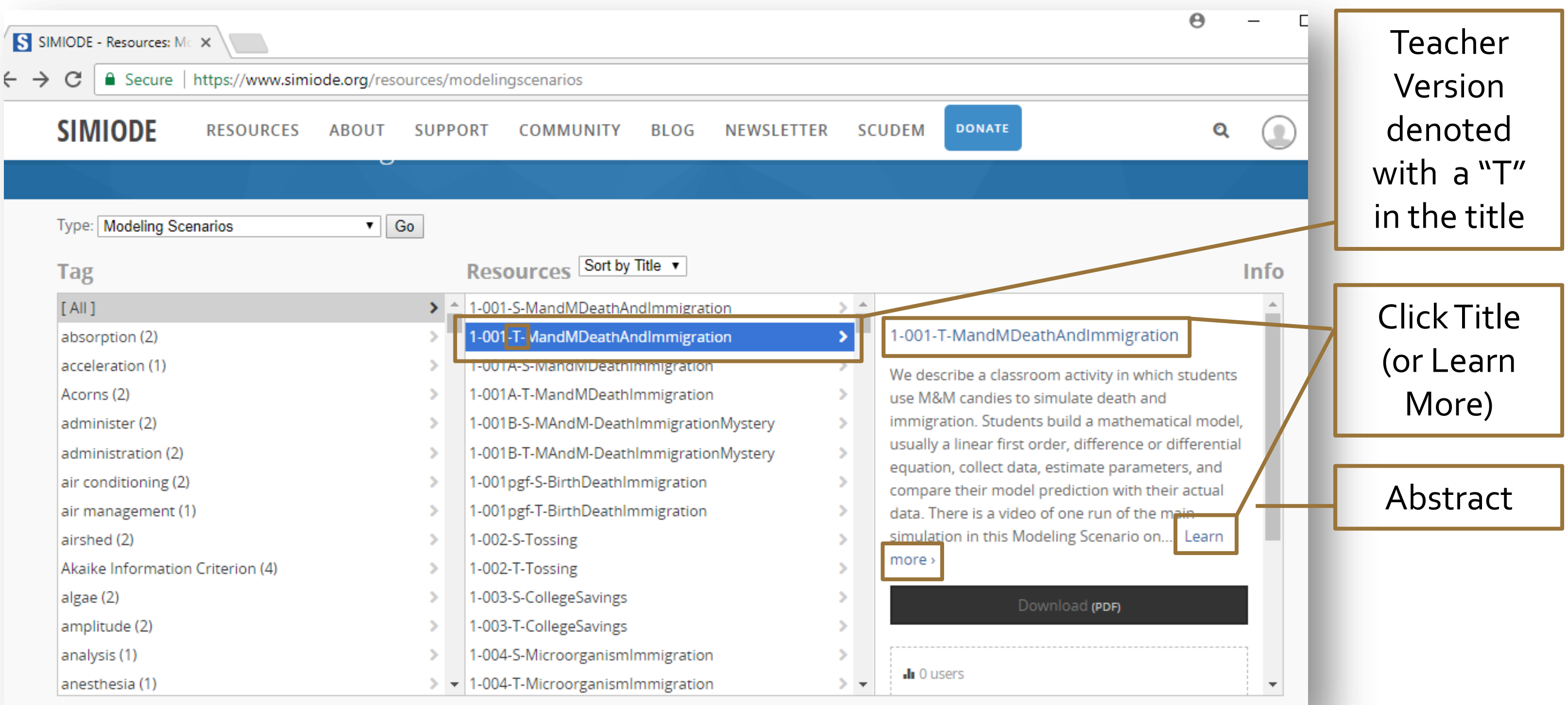
- Modeling Scenarios

  Resources -> Modeling Scenarios



Navigating SIMIODE.org

- Modeling Scenarios
  - Choose a scenario
  - Select the Teacher Version



Features of SIMIODE

- Modeling Scenarios
  - Choose a scenario and select the Teacher Version Note: Your account and teacher status must be approved by administrator before gaining access to the Teacher Version and the Supporting Docs.
  - Click the scenario title (or click Learn more >) in the right panel to be directed to the webpage dedicated to the scenario.

SIMIODE - Resources: 1-(

Secure | https://www.simiode.org/resources/116

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1-001-T-MandMDeathAndImmigration

By Brian Winkel

SIMIODE, Cornwall NY USA

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Modeling Scenarios

Published on

30 May 2015

Abstract

We describe a classroom activity in which students use M&M candies to simulate death and immigration. Students build a mathematical model, usually a linear first order, difference or differential equation, collect data, estimate parameters, and compare their model prediction with their actual data.

There is a video of one run of the main simulation in this Modeling Scenario on YouTube.

We also present a very helpful narrative about experience in using this material from John Thoo, Yuba College.

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Abstract, citation info, etc.

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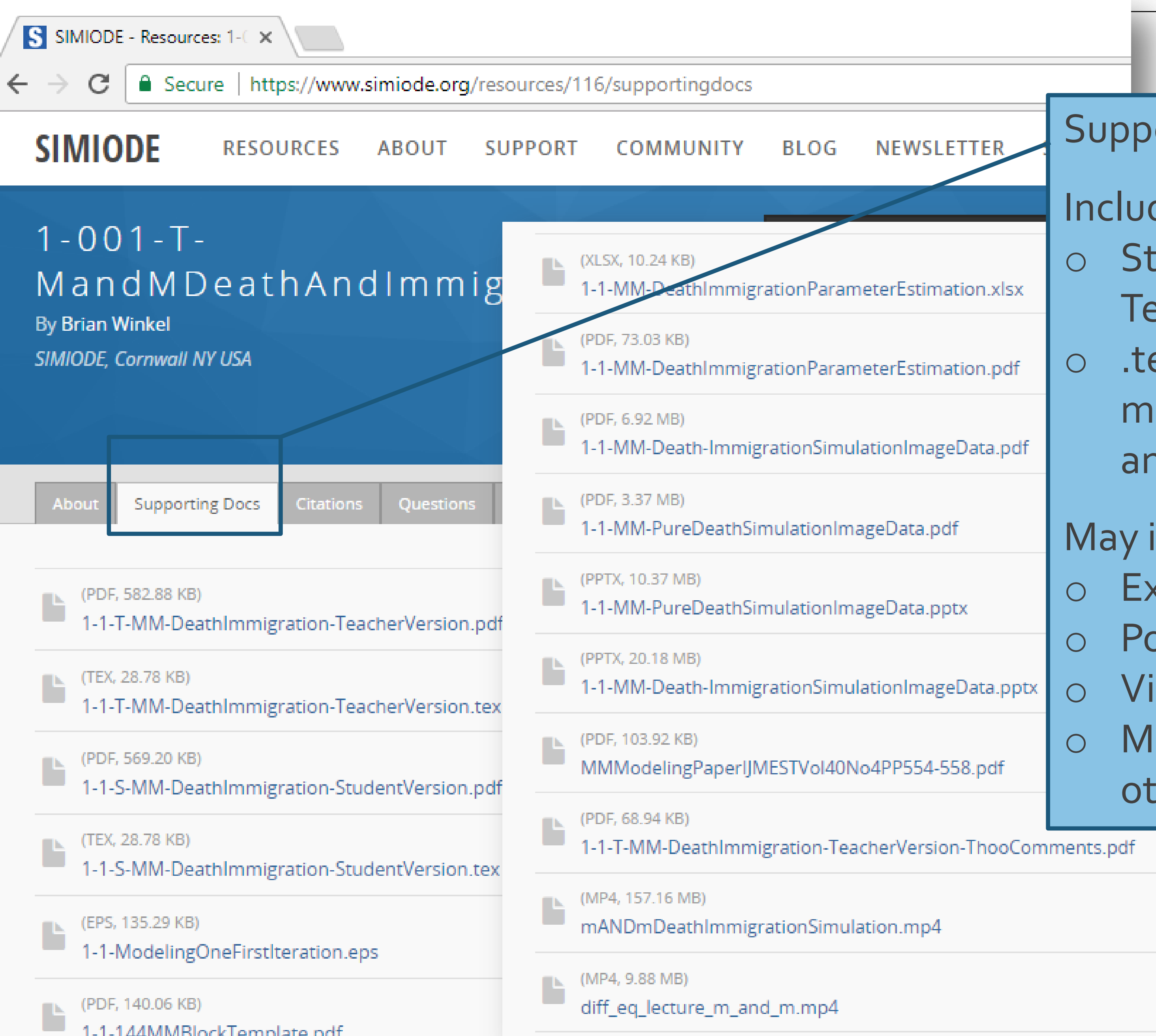


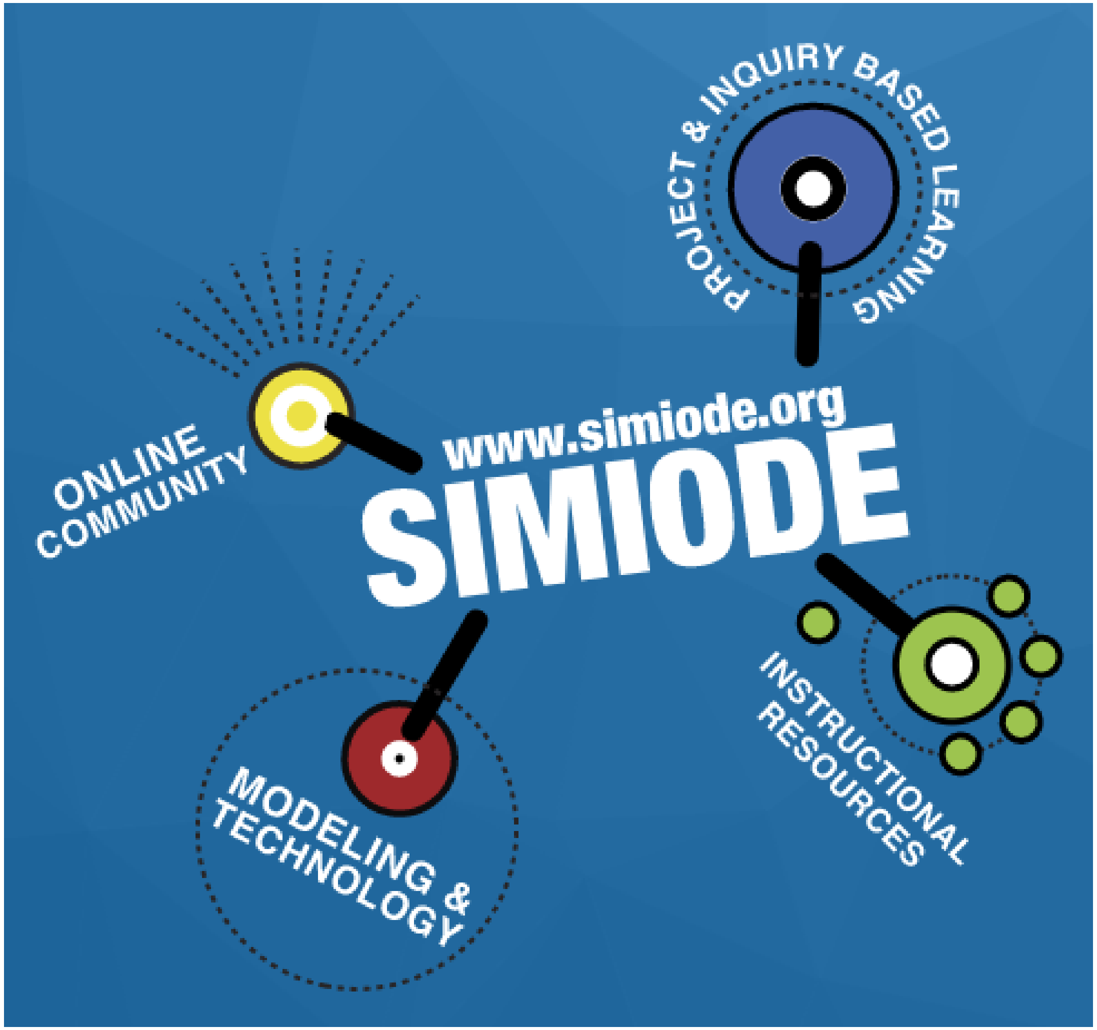
Supporting Docs

Include:

- Student and Teacher Versions
- .tex files that may be edited and customized

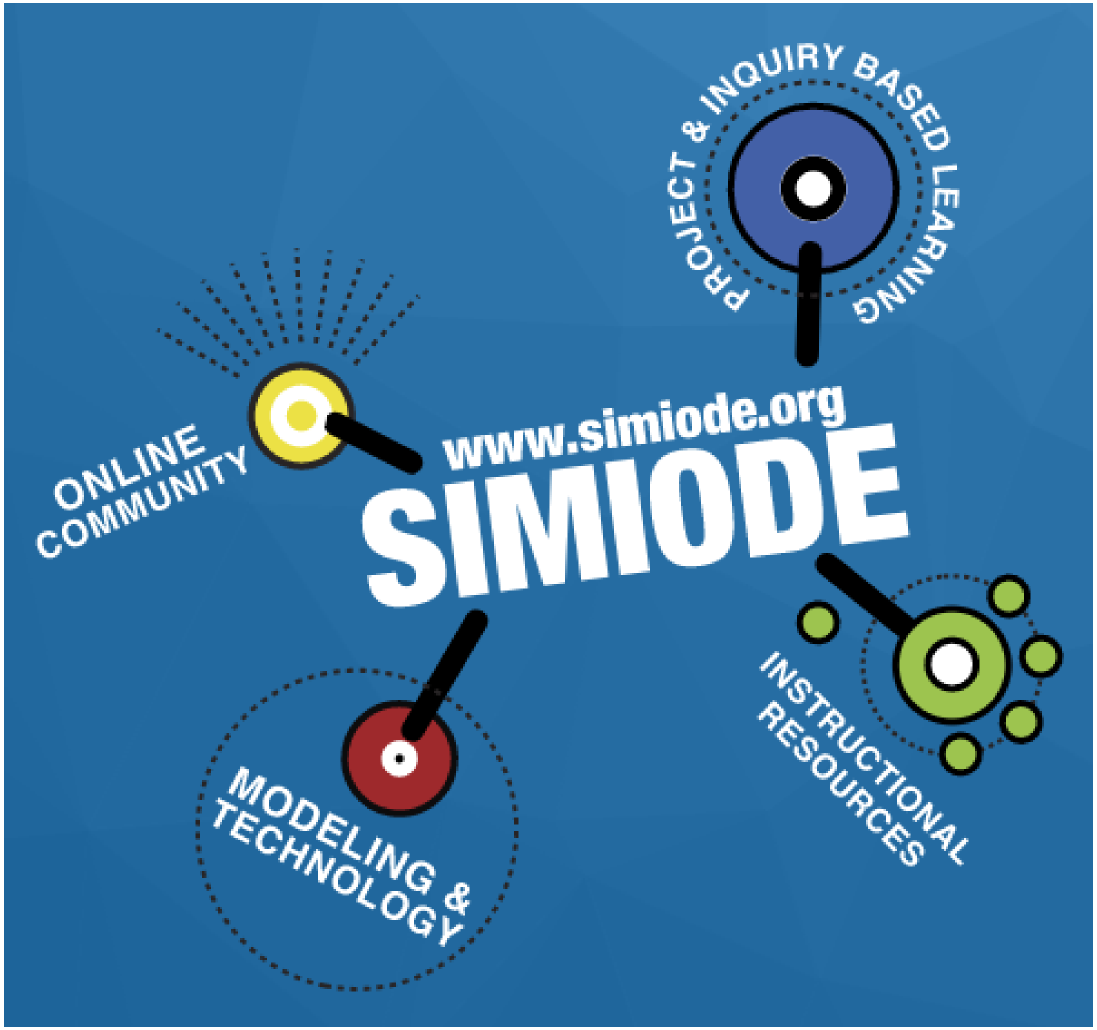
May include:

- Excel files of data
- PowerPoint
- Videos
- Mathematica or other files



SIMIODE

- Online Community
- Project & Inquiry Based Learning
- Modeling and Technology
- Instructional Resources

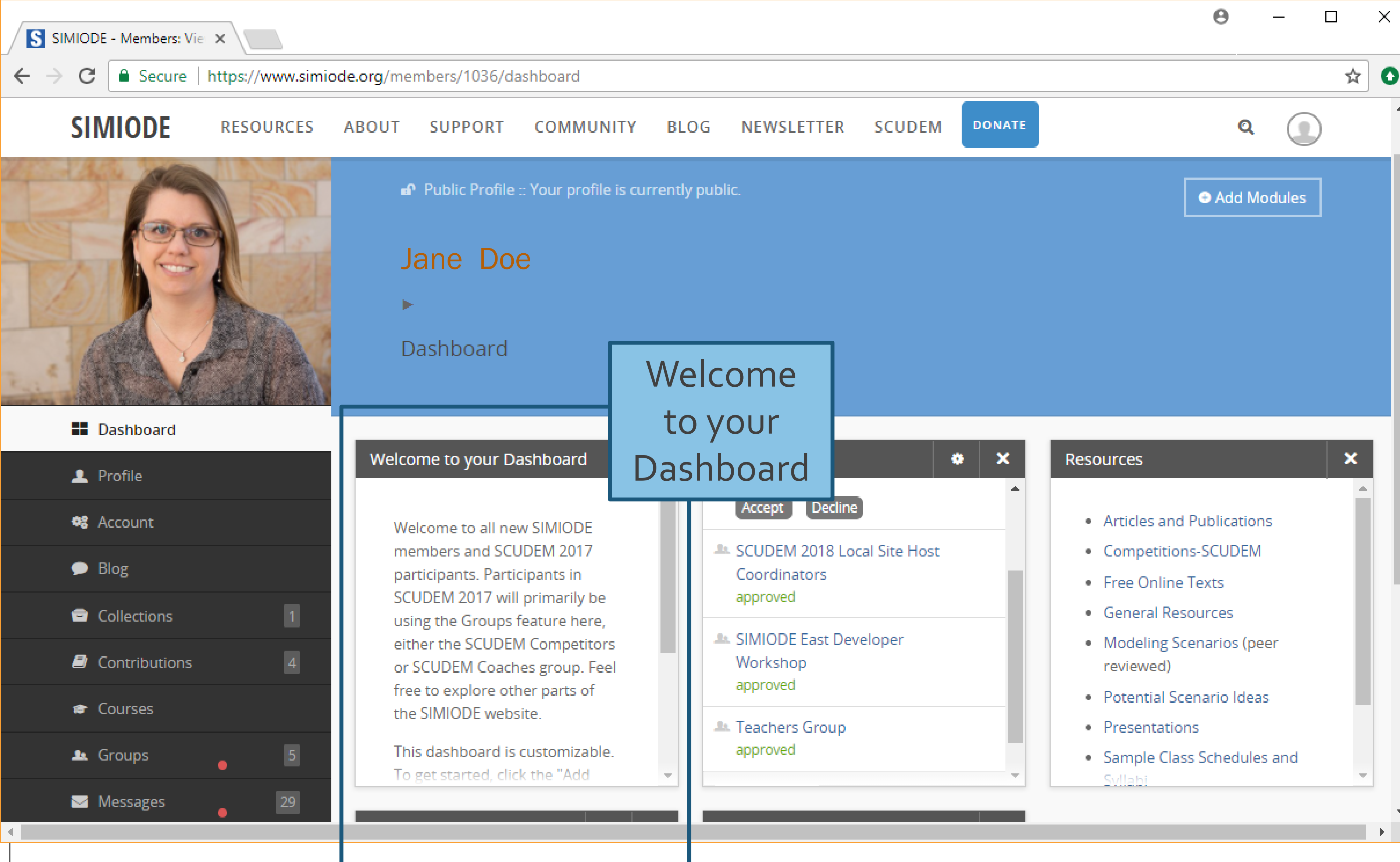


SIMIODE

- Instructional Resources include
  - Peer-reviewed modeling scenarios
  - Text materials
  - Supporting resources (e.g., slides, data, simulations)

SIMIODE

- Dashboard
  - Profile and account settings
  - Collections
  - Personal contributions and projects
  - Groups
  - Messages
  - And more!
- Customizable: Add Modules



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BLOG
NEWSLETTER
SCUDEM
DONATE
Public Profile :: Your profile is currently public.
Add Modules
Jane Doe
Dashboard
Welcome to your Dashboard
Dashboard
Profile
Account
Blog
Collections 1
Contributions 4
Courses
Groups 5
Messages 29
Welcome to your Dashboard
Welcome to all new SIMIODE members and SCUDEM 2017 participants. Participants in SCUDEM 2017 will primarily be using the Groups feature here, either the SCUDEM Competitors or SCUDEM Coaches group. Feel free to explore other parts of the SIMIODE website.
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Decline
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approved
SIMIODE East Developer Workshop
approved
Teachers Group
approved
Resources
Articles and Publications
Competitions-SCUDEM
Free Online Texts
General Resources
Modeling Scenarios (peer reviewed)
Potential Scenario Ideas
Presentations
Sample Class Schedules and

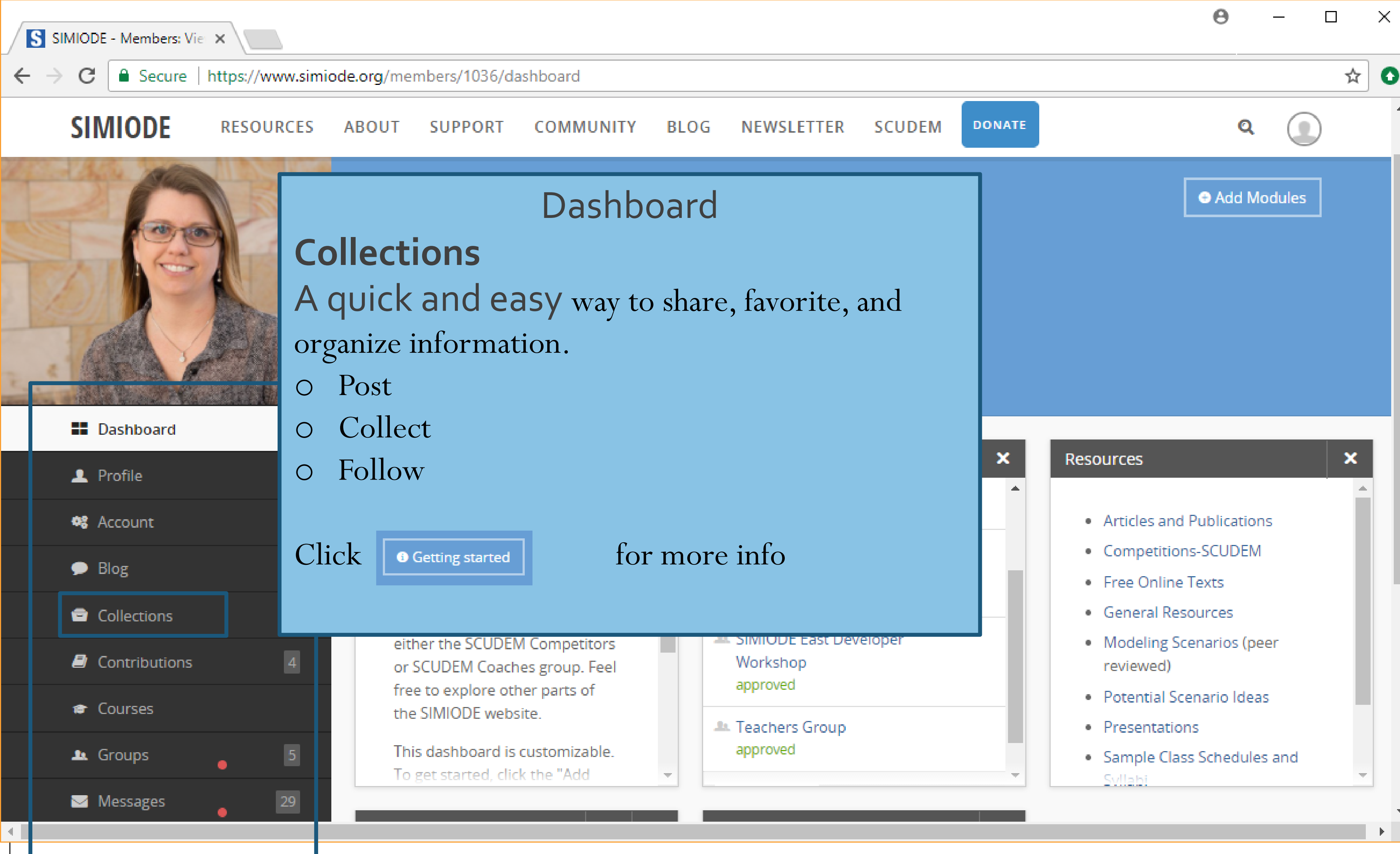
Dashboard

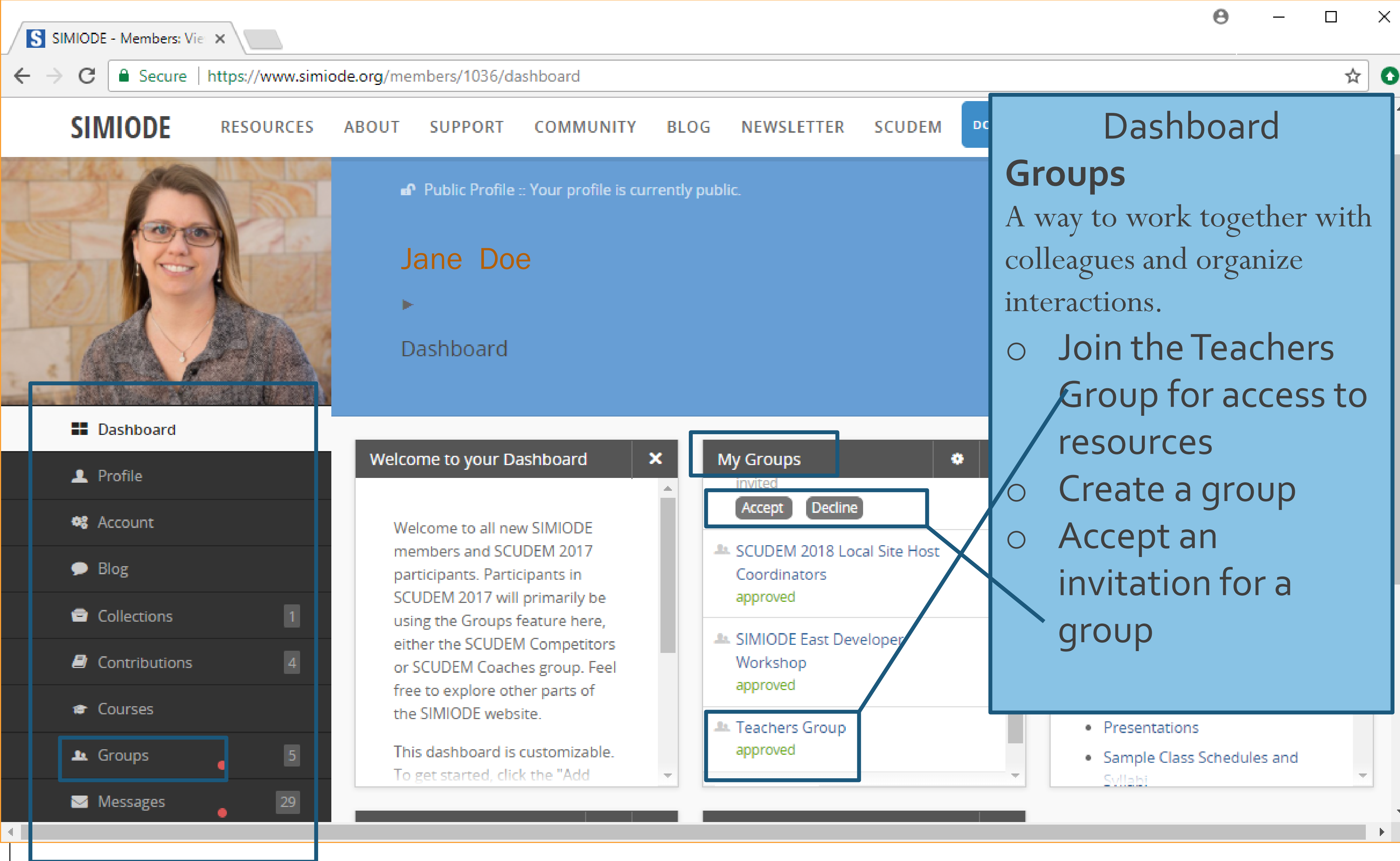
Collections

A quick and easy way to share, favorite, and organize information.

- Post
- Collect
- Follow

Click **Getting started** for more info



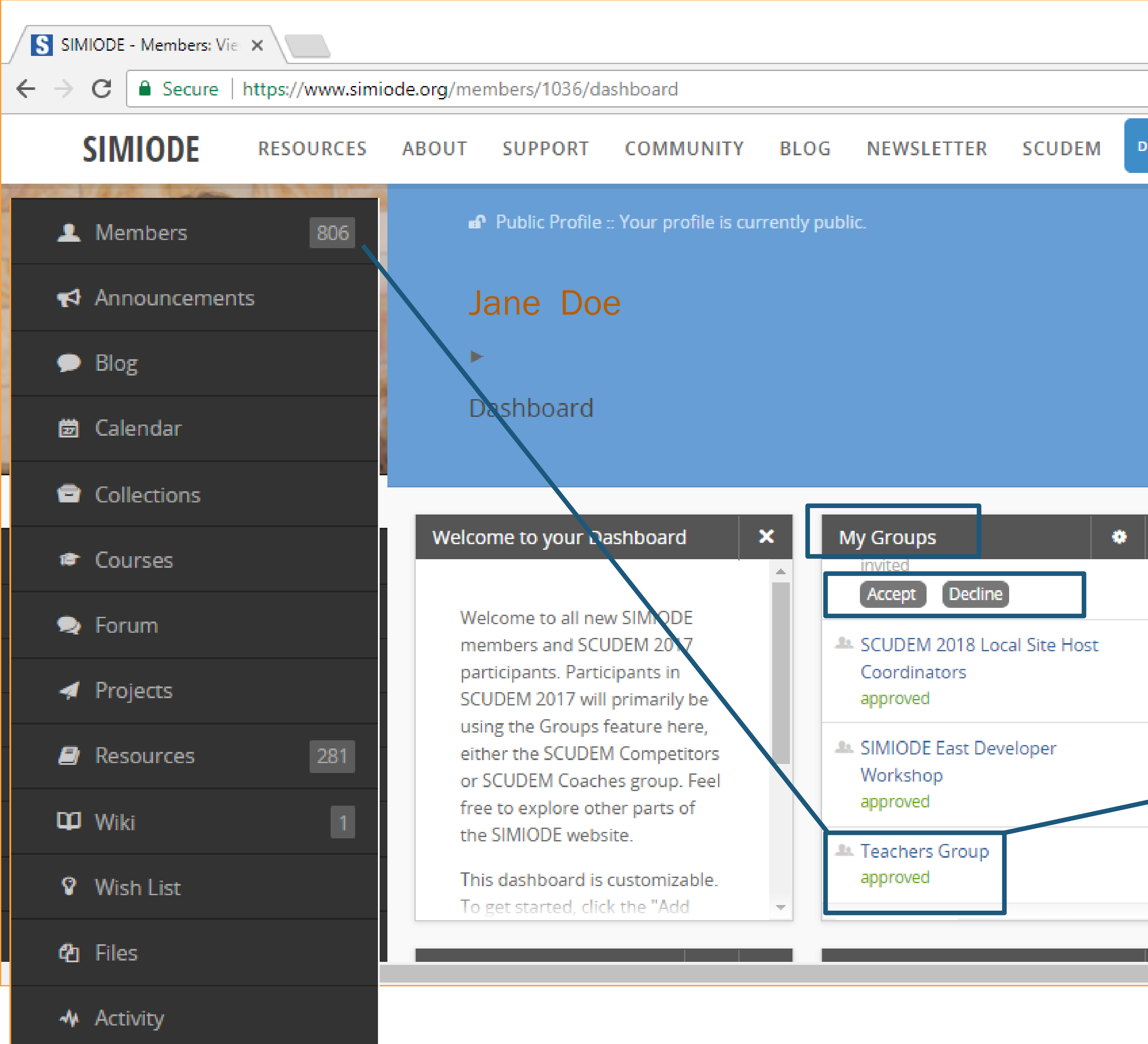


Dashboard

Groups

A way to work together with colleagues and organize interactions.

- Join the Teachers Group for access to resources
- Create a group
- Accept an invitation for a group

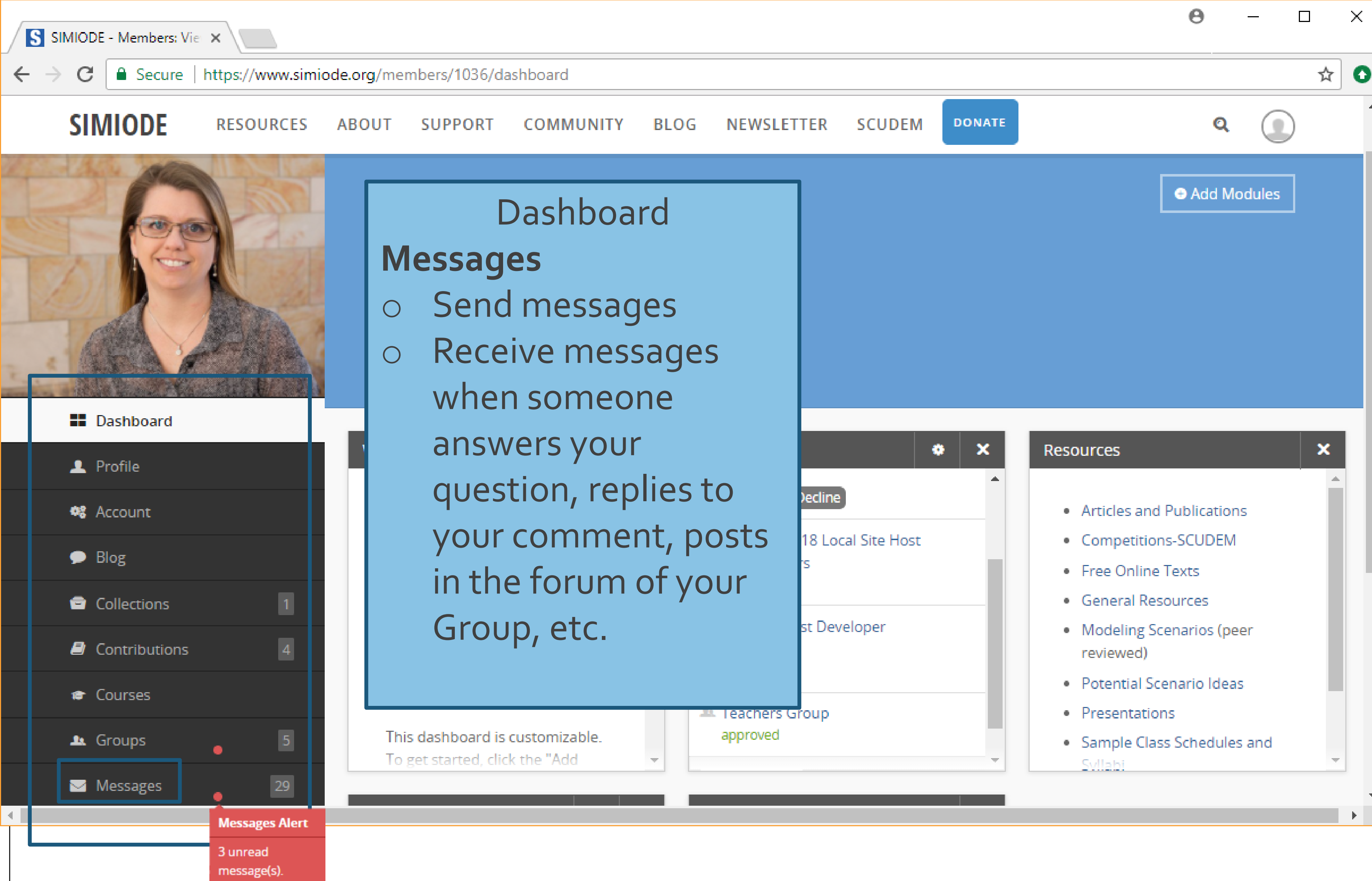


Dashboard

Groups

A way to work together with colleagues and organize interactions.

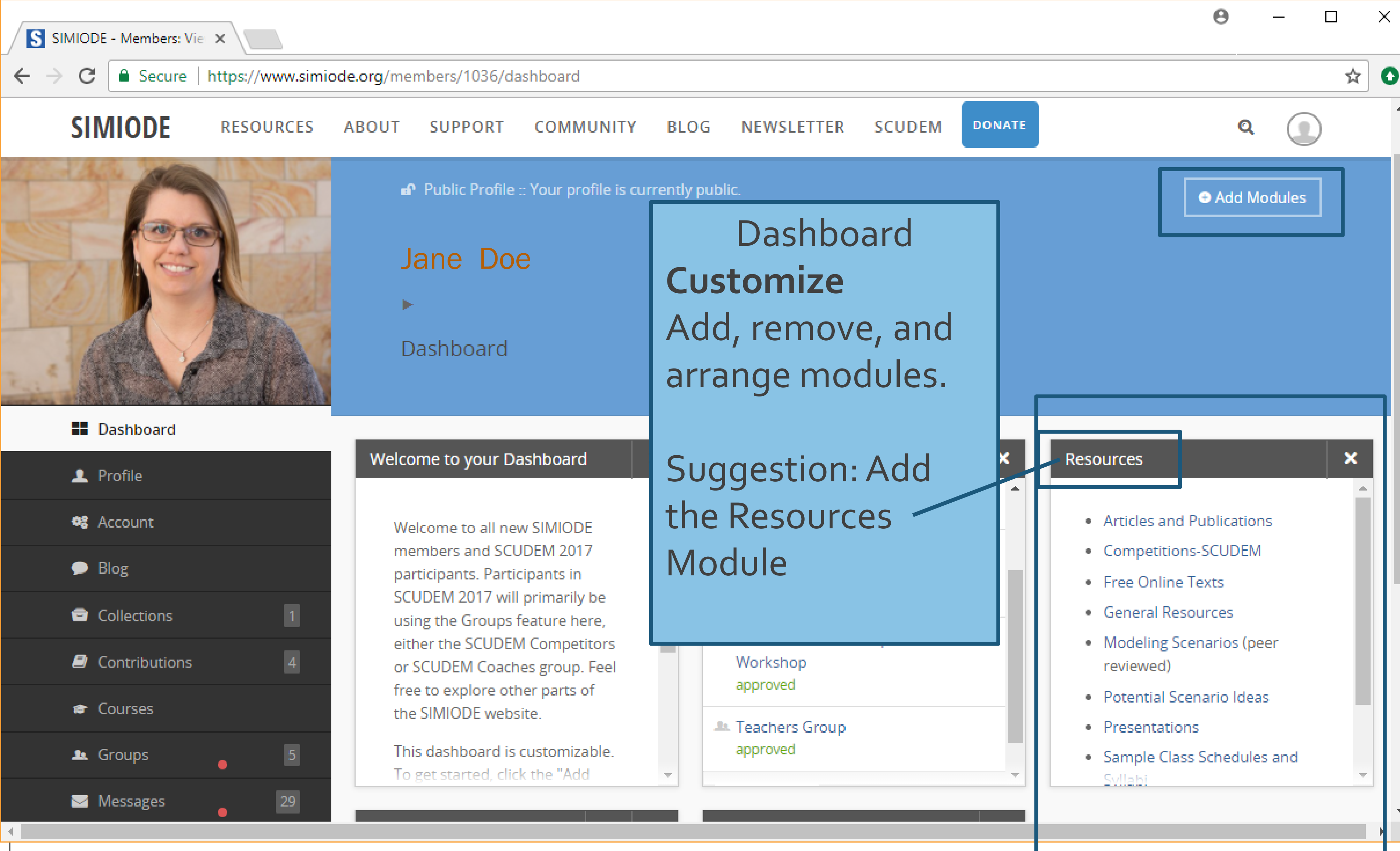
- Join the Teachers Group for access to resources
- Create a group
- Accept an invitation for a group
- Click on your group for access to:
  - Members
  - Forum
  - Files
  - And more!



Dashboard

Messages

- Send messages
- Receive messages when someone answers your question, replies to your comment, posts in the forum of your Group, etc.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DONATE
Public Profile :: Your profile is currently public.
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Jane Doe
Dashboard
Dashboard
Customize
Add, remove, and arrange modules.
Suggestion: Add the Resources Module
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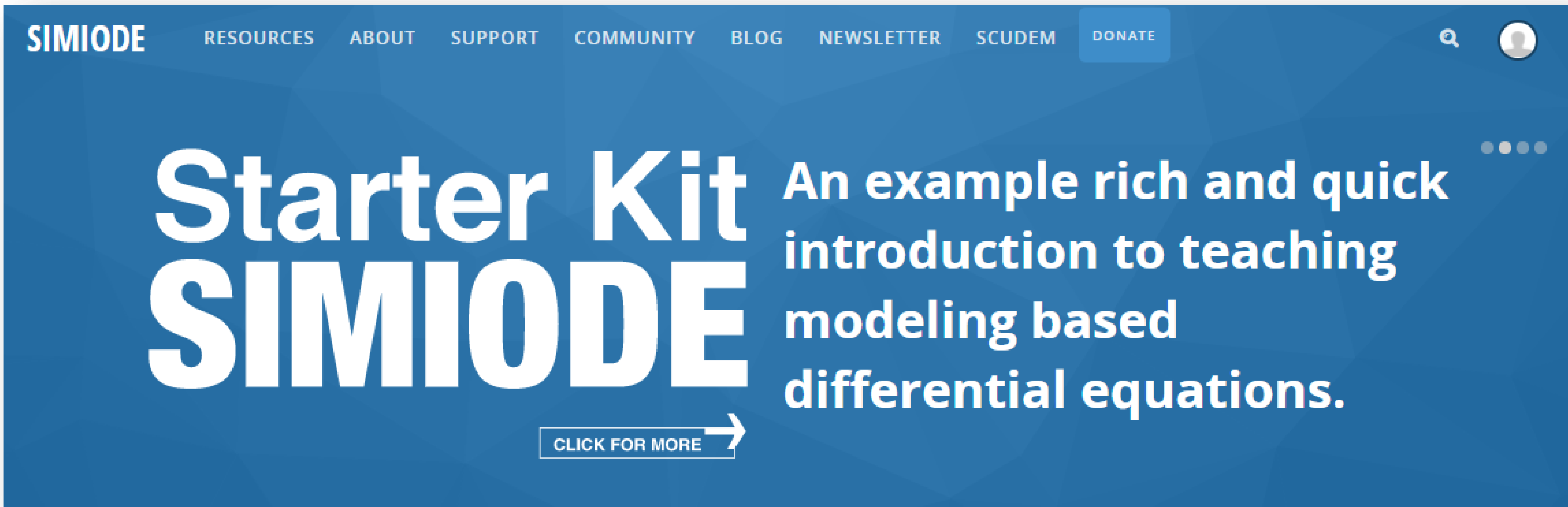
Resources on SIMIODE



- Starter Kit: https://www.simiode.org/starterkit
- Quick Start to materials for teaching Differential Equations with modeling

Resources on SIMIODE

- Starter Kit
  - First day activities
  - Modeling scenarios selected for specific topics
  - Sample syllabus
  - Resource Guide – Listing of all Modeling Scenarios
  - General Resources
    - Access 48-page document: https://simiode.org/resources/881/supportingdocs
    - Includes listing of texts, class notes, available software, etc.
  - Potential Scenario Ideas (100’s available)

Other Modeling Resources

- CODEE – Community of Ordinary Differential Equations Educators. http://www.codee.org/ .

- COMAP – Consortium for Mathematics and its Applications . www.comap.com .

- Your own modeling projects published in SIMIODE – double-blind, peer-reviewed .

Other Opportunities

- SCUDEM - SIMIODE Challenge Using
  Differential Equations Modeling
- SCUDEM IV 2019: 9 November 2019
  - simiode.org/scudem Seeking Hosts
- SIMIODE Practitioner Workshop
  - MINDE: 21-27 July 2019. George Fox University, OR
- SIMIODE Developer Workshop
  - DEMARC: 17-21 July 2019. George Fox University, OR
    simiode.org/nsf2019workshops Apply anytime.