Welcome to MATH 256

Differential equations (for Chemical and Biological Engineering students)

Instructor:
Prof. Eric Cytrynbaum

Course goals

- Primary: Learn to solve ordinary and partial differential equations (mostly linear first and second order DEs).

- Secondary: Learn to use DEs to model physical, chemical, biological systems (really just an intro to this skill).

Prerequisites

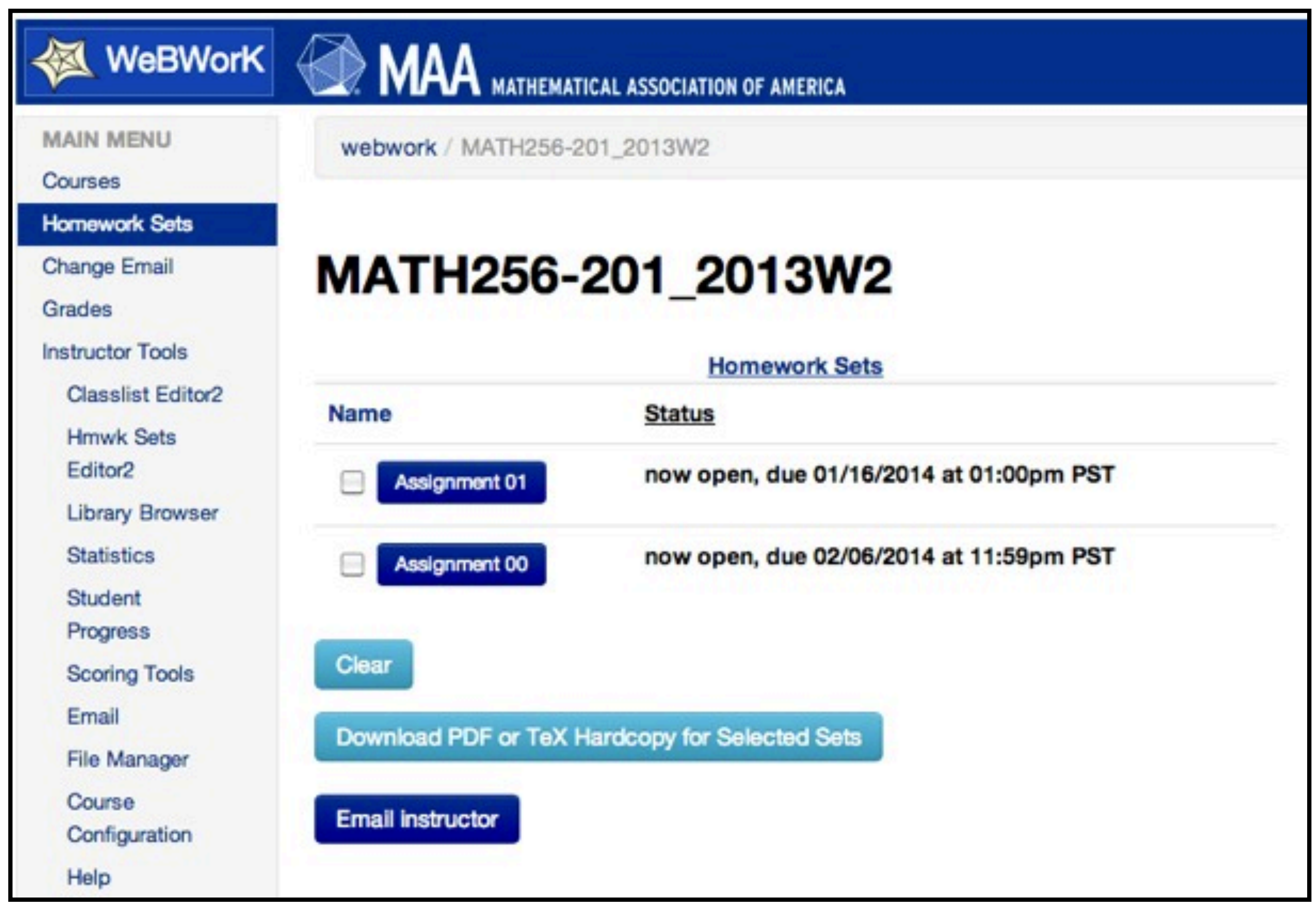
- First year calculus (MATH 100/101).
- Linear algebra (MATH 152).
- Multivariable calculus (MATH 200 or 253).
- Talk to me if you aren’t sure that you’re prepared for this course.

Tools we'll be using this term

- WeBWorK for homework assignments.
- Piazza for online discussion.
- Clickers for in-class responses.
- ~~Cell phones and facebook for getting distracted during lectures and while studying~~.

WeBWorK

- Online homework system.
- https://webwork.elearning.ubc.ca/webwork2/MATH256-201_2013W2
- Log in using your CWL.



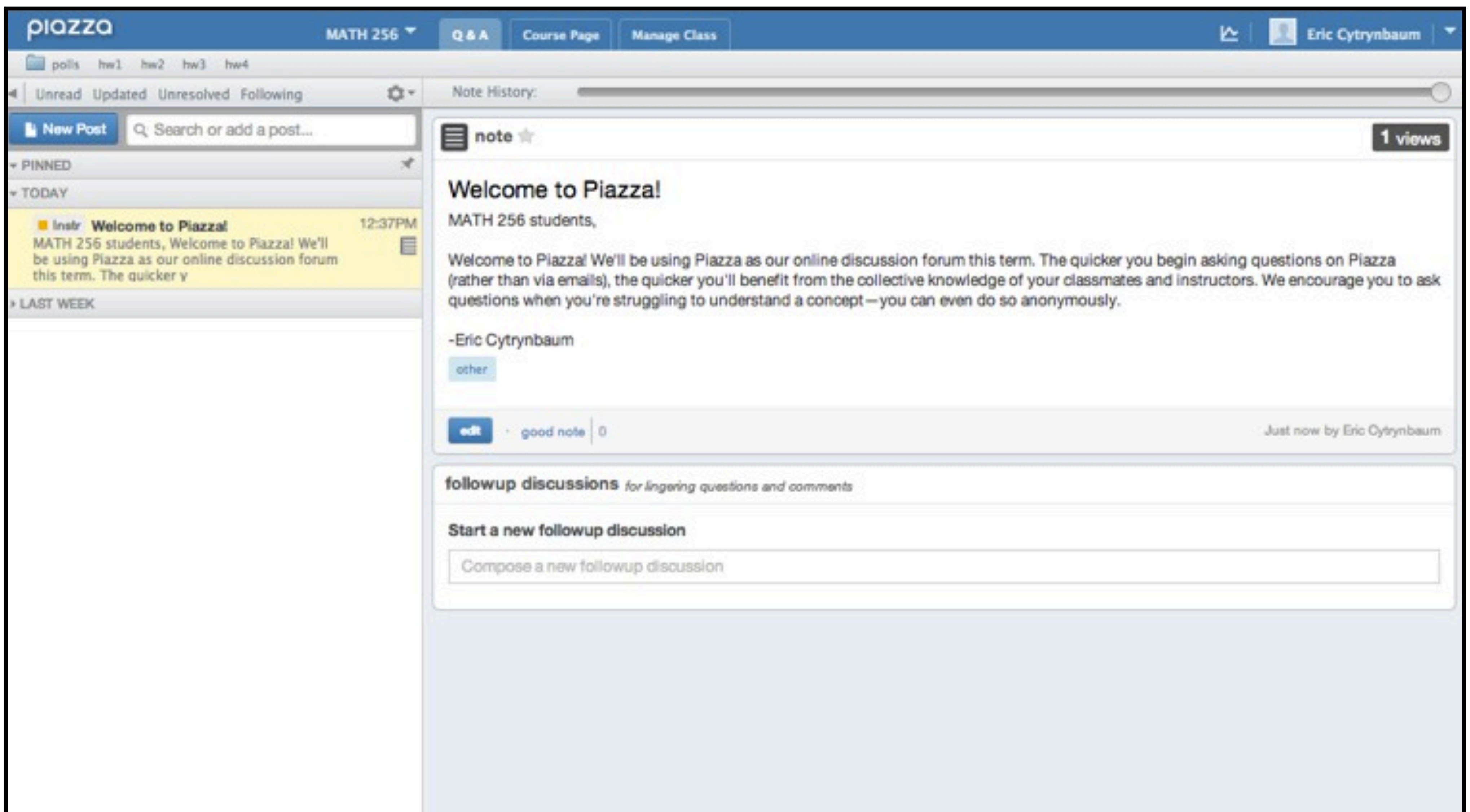
Why WeBWorK?

- Automated marking (instant feedback).
- Free for students (unlike hw systems provided by textbook companies).
- Stable, open source, widely used at UBC and many other universities.
- Have you used WeBWorK previously?   (A) Yes. (B) No.

Piazza

- Online discussion forum.

- Sign up at https://piazza.com



Why Piazza?

- Get faster responses to your questions.
- See what your classmates are asking about.
- Connect with others in the class who are looking for study partners.
- Have you used Piazza previously?   (A) Yes. (B) No.

Clickers

- Personal response system.
- Register your clicker at https://connect.ubc.ca

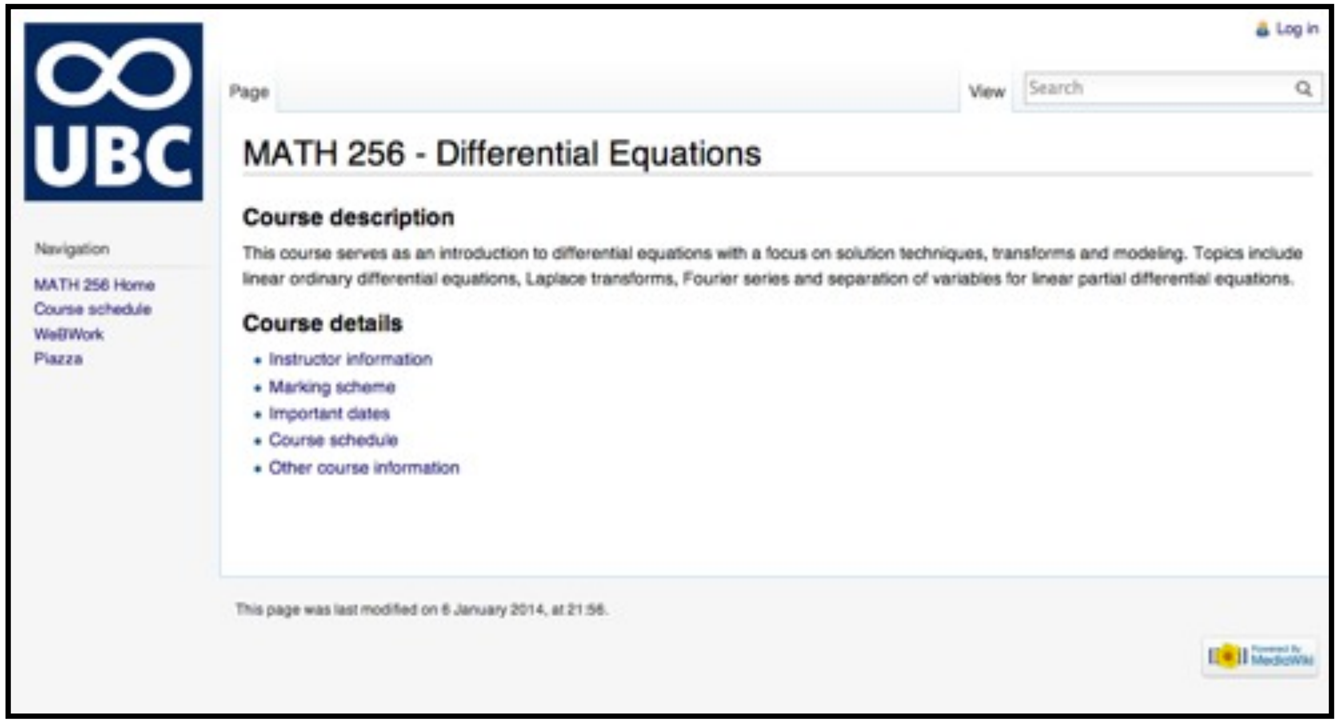
Why clickers?

- Active learning - you should be thinking during class.
- My goal is to make clicker Qs that many of you get wrong - they help us to target what you don’t understand yet.
- Points are for (thinking and then) clicking, not for getting answers correct.
- I don’t look at the results on an individual basis so they are effectively anonymous.
- Have you used clickers previously? (A) Yes. (B) No.

More info online...

- Check the course website for
    - office hour info,
    - info on additional help,
    - textbook,
    - course policies (e.g. marking scheme)
    - week-by-week schedule.

- https://wiki.math.ubc.ca/mathbook/M256/MATH_256_-_Differential_Equations



Felix Baumgartner's freefall from 40 km up

- Newton says F_{net}=ma or

$$ma = -mg + kv^2$$

- A differential equation in disguise because

$$a = v'$$

- so the equation is really a DE for v(t)!

$$mv' = -mg + kv^2$$

- Simple model to predict how fast he'll go, how long it will take etc.

Felix Baumgartner's freefall from 40 km up

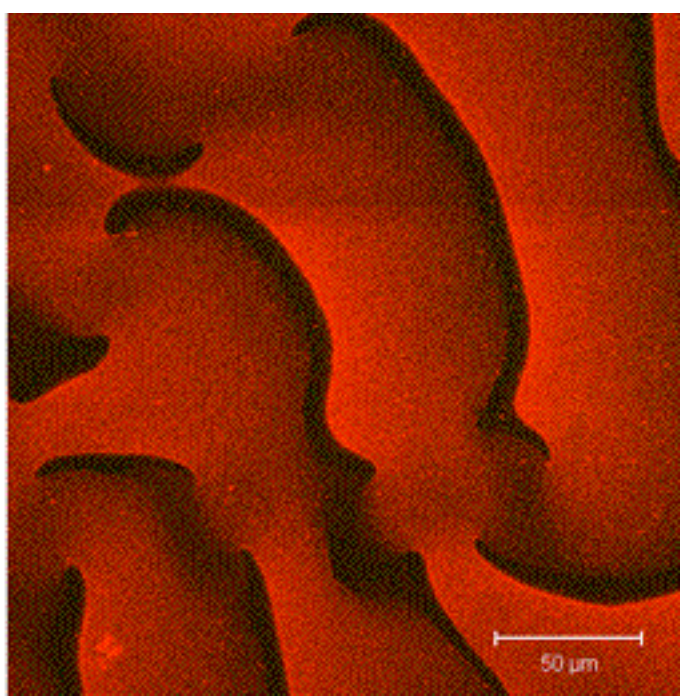
$$mv' = -mg + kv^2$$

- Flaws with this model?
- g is not constant...
- ...but 6371 km ≈ 6411 km so not bad.
- k is not constant either (depends on air density) - this is significant!

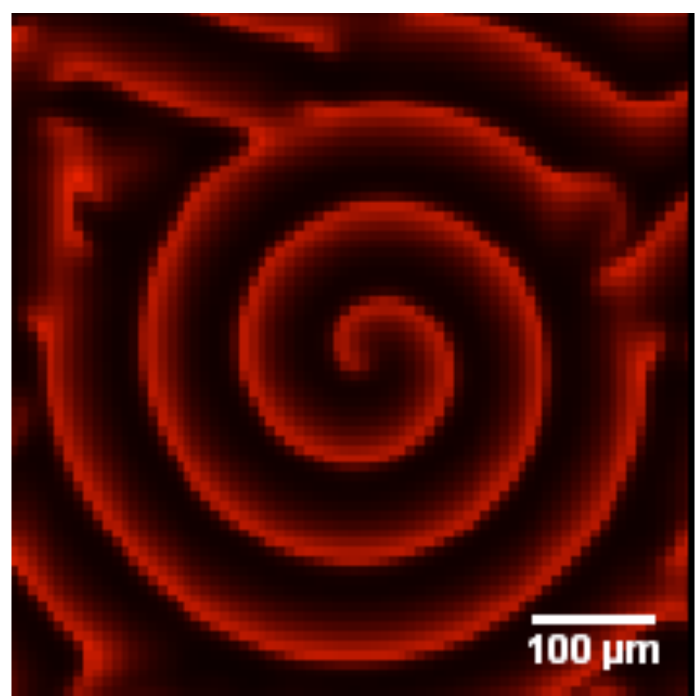
A bacterial cell division regulator

- Two interacting bacterial proteins that undergo complicated dynamics.
- Differential equation model help understand how they work.

Experiment



Model



$$\frac{\partial u}{\partial t} = u - uv + D\frac{\partial^2 u}{\partial x^2}$$

$$\frac{\partial v}{\partial t} = uv - v + D\frac{\partial^2 v}{\partial x^2}$$

Classifying DEs (Section 1.3)

- Ordinary differential equation (ODE) - a DE that involves derivatives of a function with respect to only one independent variable.

Logistic equation: $$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$$

Beam equation: $$EI\frac{d^4w}{dx^4} = q$$

- Partial differential equation (PDE) - a DE that involves derivatives of a function with respect to more than one independent variable.

Heat/diffusion equation: $$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2}$$

Wave equation: $$\frac{\partial^2 u}{\partial t^2} = c^2\frac{\partial^2 u}{\partial x^2}$$

Classifying DEs (Section 1.3)

- Order of a DE - order of the highest derivative in the equation.
- e.g. Heat/diffusion equation: $$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2}$$
    - First order in time (t), second order in space (x).

Beam equation:

$$EI\frac{d^4 w}{dx^4} = q$$

Wave equation:

$$\frac{\partial^2 u}{\partial t^2} = c^2\frac{\partial^2 u}{\partial x^2}$$

Logistic equation:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$$

- Order (in time):
- Order (in space):

(A) first order

(B) second order

(C) third order

(D) fourth order

Classifying DEs (Section 1.3)

- Linearity - a DE is linear if it is linear in the unknown function and all its derivatives.

- (A) Linear or (B) nonlinear:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) = rP - \frac{r}{K}P^2$$ <--- Nonlinear

$$EI\frac{d^4w}{dx^4} = q$$ <--- Linear

$$t^2\frac{dy}{dt} + y = \sin(t)$$ <--- Linear

$$t^2\frac{dy}{dt} + y^2 = \sin(t)$$ <--- Nonlinear

More definitions - solutions

- Solution to a DE on some interval A
    - a function that is suitable differentiable everywhere in A (i.e. has as many derivatives as appear in the equation) and,
    - satisfies the equation.

- Arbitrary constant - a constant that does not appear in the DE but arises while solving the equation (usually at an integration step).

- A particular solution - a solution with no arbitrary constants in it.

- The general solution - a solution with one or more arbitrary constants that encompass ALL possible solutions to the DE.

Verifying that a function is a solution

- Plug it in and make sure it satisfies the equation.

A cylindrical bucket has a hole in the bottom. If $h(t)$ is the height of the water at any time t in hours, then the differential equation describing this leaky bucket is given by the equation:

$$\frac{dh(t)}{dt} = -6\sqrt{h(t)}.$$

If initially, there are 4 inches of water in the bucket $(h(0) = 4)$, what is the solution to this differential equation?

A. $h(t) = (2 - 3t)^2$ ←
B. $h(t) = \sqrt{16 - 2t}$
C. $h(t) = (3 - 3t)^2$
D. $h(t) = 4 - 6t^2$

For this one, "brute force checking" is expected as we don't have a technique to handle this type yet.

Method of integrating factors (Section 2.1)

$$\frac{d}{dt}\left(t^2 y(t)\right) =$$

(A) $2t\dfrac{dy}{dt}$

(B) $t^2\dfrac{dy}{dt}$

(C) $2ty$

(D) $t^2\dfrac{dy}{dt} + 2ty$

Method of integrating factors (Section 2.1)

$$\frac{d}{dt}\left(t^2 y(t)\right) =$$

(A) $2t\dfrac{dy}{dt}$

(B) $t^2\dfrac{dy}{dt}$

(C) $2ty$

(D) $t^2\dfrac{dy}{dt} + 2ty$

Method of integrating factors (Section 2.1)

- Given that $\dfrac{d}{dt}\left(t^2 y(t)\right) = \; t^2 \dfrac{dy}{dt} + 2ty$

- if you're given the equation $t^2 \dfrac{dy}{dt} + 2ty = 0$

- you can rewrite is as $\dfrac{d}{dt}\left(t^2 y(t)\right) = 0$

arbitrary constant
that appeared at an
integration step

- so the solution is $t^2 y(t) = C$ or equivalently $y(t) = \dfrac{C}{t^2}$.

Method of integrating factors (Section 2.1)

- Solve the equation $t^2\dfrac{dy}{dt} + 2ty(t) = \sin(t)$ (not brute force checking).

(A) $y(t) = -\dfrac{1}{t^2}\sin(t)$

(B) $y(t) = -\cos(t) + C$

(C) $y(t) = \dfrac{C - \cos(t)}{t^2}$

(D) $y(t) = \sin(t) + C$

(E) $y(t) = -\dfrac{1}{t^2}\cos(t)$

Method of integrating factors (Section 2.1)

- Solve the equation $t^2\dfrac{dy}{dt} + 2ty(t) = \sin(t)$ (not brute force checking).

(A) $y(t) = -\dfrac{1}{t^2}\sin(t)$

(B) $y(t) = -\cos(t) + C$

(C) $y(t) = \dfrac{C - \cos(t)}{t^2}$

general solution (although that's not obvious)

(D) $y(t) = \sin(t) + C$

a particular solution

(E) $y(t) = -\dfrac{1}{t^2}\cos(t)$

Initial conditions (IC) and initial value problems (IVP)

- An initial condition is an added constraint on a solution.
- e.g. Solve $t^2 \dfrac{dy}{dt} + 2ty(t) = \sin(t)$ subject to the IC $y(\pi) = 0$.

(A) $y(t) = -\dfrac{C + \cos(\pi)}{\pi^2}$

(B) $y(t) = -\dfrac{1 - \cos(t)}{t^2}$

(C) $y(t) = \dfrac{1 + \cos(t)}{t^2}$

(D) $y(t) = -\dfrac{1 + \cos(t)}{t^2}$

- An Initial Value Problem (IVP) is a ODE together with an IC.

Method of integrating factors (Section 2.1)

- A few examples - for each one, find a function f(t) to multiply through by so that the left hand side becomes a product rule:

[illegible]

Method of integrating factors (Section 2.1)

$$t\frac{dy}{dt} + 2y(t) = 1 \qquad \longrightarrow f(t) = t$$

$$t^2\frac{dy}{dt} + 4ty(t) = \frac{1}{t} \qquad \longrightarrow f(t) = t^2$$

$$\frac{dy}{dt} + y(t) = 0 \qquad \longrightarrow f(t) = e^t$$

$$\frac{dy}{dt} + \cos(t)y(t) = 0 \qquad \longrightarrow f(t) = e^{\sin(t)}$$

$$\frac{dy}{dt} + g'(t)y(t) = 0 \qquad \longrightarrow f(t) = e^{g(t)}$$

Method of integrating factors (Section 2.1)

- General case - all first order linear ODEs can be written in the form

$$\frac{dy}{dt} + p(t)y = q(t)$$

- The appropriate integrating factor is $e^{\int p(t)dt}$.

- The equation can be rewritten $\frac{d}{dt}\left(e^{\int p(t)dt}y\right) = e^{\int p(t)dt}q(t)$ which is solvable provided you can find the antiderivative of the right hand side.