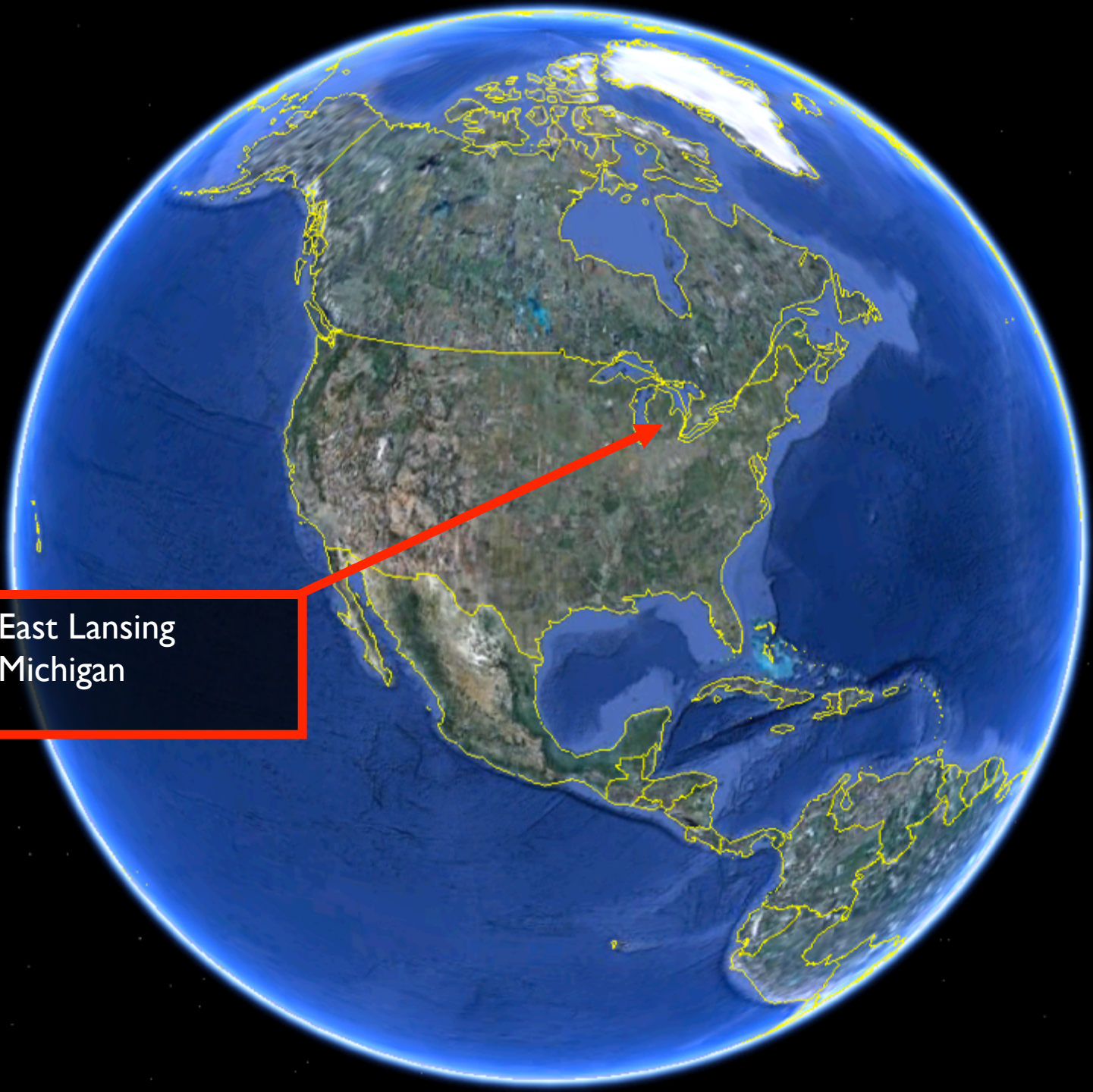


# INTEGRATING CORE COMPETENCIES IN ENGINEERING EDUCATION

Wolfgang Bauer

Michigan State University

East Lansing  
Michigan







# MICHIGAN STATE UNIVERSITY

- ▶ Premier land-grant university (est. 1855)
  - ▶ 5,200-acre campus with 2,100 acres in existing or planned development
  - ▶ 577 buildings, including 83 with instructional space
- ▶ 36,500 undergraduate and 11,000 graduate student from 130 countries (53% women)
- ▶ ~430,000 living alumni
- ▶ ~5,000 faculty and academic staff
- ▶ 17 colleges, 200 different programs of study
- ▶ Top-100 university in the World

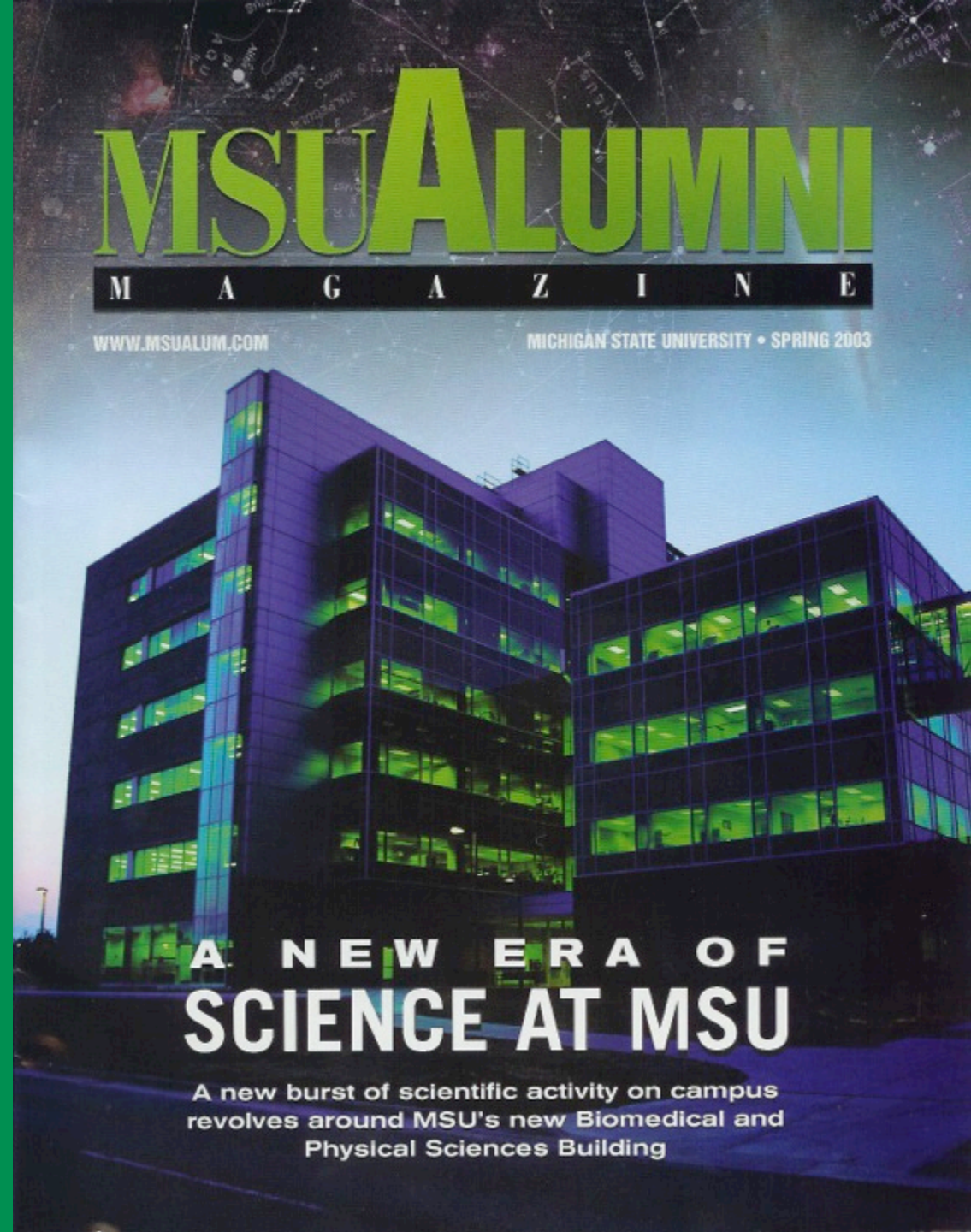


# Department of Physics And Astronomy

Nuclear Physics (#1 in USA)  
Particle Physics  
Condensed Matter Physics  
Astronomy

\$8M annual budget  
\$30M federal grants

70 faculty (all ranks)



# CONVENTIONAL CURRICULUM

## ► Calculus 1, 2, 3 – MSU Courses:

- MTH132 (Calculus 1): Limits, continuous functions, derivatives and their applications. Integrals and the fundamental theorem of calculus.
- MTH133 (Calculus 2): Applications of the integral and methods of integration. Improper integrals. Polar coordinates and parametric curves. Sequences and series. Power series.
- MTH234 (Multivariable Calculus): Vectors in space. Functions of several variables and partial differentiation. Multiple integrals. Line and surface integrals. Green's and Stokes's theorems.

## ► Physics 1, 2, 3 – MSU Courses:

- PHY183 (Physics for Scientists and Engineers 1): Mechanics, Newton's laws, momentum, energy conservation laws, rotational motion, oscillation, gravity, and waves.
- PHY184 (Physics for Scientists and Engineers 2): Electricity and magnetism, electromagnetic waves, light and optics, interference and diffraction.
- PHY215 (Thermodynamics and Modern Physics): Thermodynamics, atomic physics, quantized systems, nuclear physics, solids, elementary particles.
- PHY191, PHY192 (Physics Lab for Scientists 1&2)



# CONVENTIONAL CURRICULUM

## ► Computer Science I, 2 – MSU Courses:

- CSE231 (Introduction to Programming 1): Introduction to programming using Python. Design, implementation and testing of programs to solve problems such as those in engineering, mathematics and science. Programming fundamentals, functions, objects, and use of libraries of functions.
- CSE232 (Introduction to Programming 2): Continuation of object-centered design and implementation in C++. Building programs from modules. Data abstraction and classes to implement abstract data types. Static and dynamic memory allocation. Data structure implementation and algorithm efficiency. Lists, tables, stacks, and queues. Templates and generic programming.

# SHORTCOMINGS

- ▶ Students see different disciplines as not connected
- ▶ Concepts in mathematics are not applied to physics and engineering
- ▶ Only analytically solvable cases are addressed
- ▶ Numerical analysis is not connected to mathematics
- ▶ Computer skills are not applied to physics and engineering problems
- ▶ Real-world complications are ignored




# NEW APPROACH: FYIE

## First Year Integrated Engineering (FYIE)

- ▶ Replace Mathematics, Physics, and Computer Science Course by one integrating block course
- ▶ Problem-Based Learning (PBL) course
  - ▶ Central instructional unit is a problem, which needs to be solved by integrating the different disciplines
  - ▶ Not lecture-centered
  - ▶ Flipped classroom, using internet based lesson vignettes (5 – 10 minutes duration)
- ▶ SCALE-UP style classroom
  - ▶ Encourages collaboration
  - ▶ Students work in collaborative work teams

# CORE TEAM (MICHIGAN STATE UNIVERSITY)

Bauer, Wolfgang	Physics
Bell, Bob	Mathematics
Briedis, Daina	Engineering
Esfahanian, Abdol	Engineering
Geier, Bob	Mathematics
Genik, Laura	Engineering
Grabill, Jeff	Writing
Hinds, Timothy	Engineering
Hjorth-Jensen, Morten	Physics (University of Oslo, Norway)
Idema, Amanda	Engineering
Keller, Brin	Mathematics
Punch, Bill	Computer Science
 Sticklen, Jon	Computer Science
Syldic, Mary Anne	Evaluator (Western Michigan University)
Tessmer, Stuart	Physics
Urban-Lurain, Mark	Computer Science
Vergara, Claudia	Engineering
Walton, Pat	Engineering
Wolff, Tom	Engineering



# TRAJECTORIES

## ► Mathematics

- Differential Equations for motion with constant acceleration  $g$

$$\frac{dv_x}{dt} = 0$$

$$\frac{dx}{dt} = v_x$$

$$\frac{dv_y}{dt} = -g$$

$$\frac{dy}{dt} = v_y$$

## ► Solution

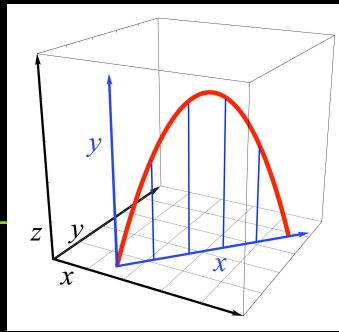
$$v_x(t) = v_{x0}$$

$$v_y(t) = v_{y0} - gt$$

$$x(t) = x_0 + v_{x0}t$$

$$y(t) = y_0 + v_{y0}t - \frac{1}{2}gt^2$$

# TRAJECTORIES



## ► Physics

### ► Live lecture demonstrations or videos

- Independence of x and y motion
- Projectile motion
- Free-fall

### ► Derivations and Extensions – Applications of Calculus

- Parabolic trajectory

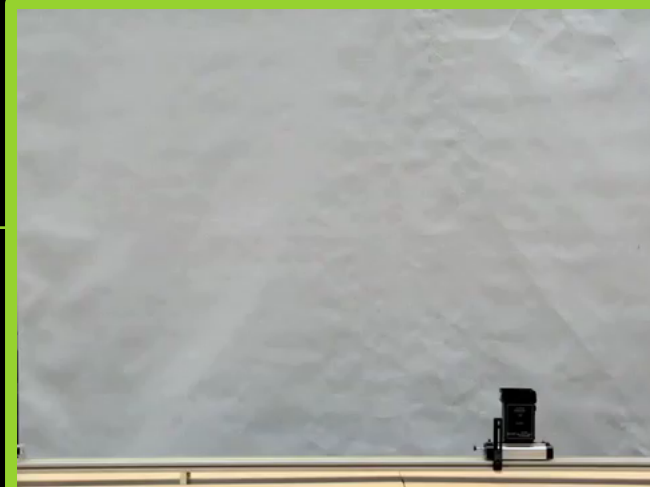
$$y = \left( y_0 - \frac{v_{y0}x_0}{v_{x0}} - \frac{gx_0^2}{2v_{x0}^2} \right) + \left( \frac{v_{y0}}{v_{x0}} + \frac{gx_0}{2v_{x0}^2} \right) x - \frac{g}{2v_{x0}^2} x^2$$

- Range of projectiles

$$R = \frac{v_0^2}{g} \sin 2\theta_0$$

- Maximum height of projectiles

$$H = y_0 + \frac{v_{y0}^2}{2g}$$





# TRAJECTORIES

## ► Interactive simulations (html5)



# TRAJECTORIES

## ► E-Book

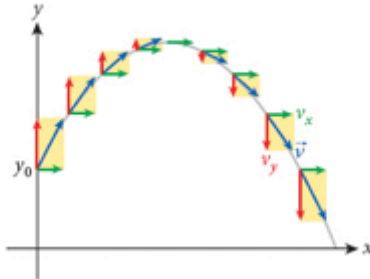
McGraw-Hill Connect – Ebook

connect.mcgraw-hill.com/connect/hmEBook.do?setTab=sectionTabs

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go which is also the local slope of the flight path. At the top of the trajectory, the green and blue arrows are identical because the velocity vector has only an  $x$ -component—that is, it points in the horizontal direction.




The figure shows a parabolic trajectory in a 2D Cartesian coordinate system with  $x$  and  $y$  axes. The trajectory starts at a point  $y_0$  on the  $y$ -axis. At several points along the path, velocity vectors  $\vec{v}$  are shown as blue arrows. At each of these points, the velocity is decomposed into its horizontal component  $v_x$  (green arrow) and vertical component  $v_y$  (red arrow). Yellow shaded regions highlight the velocity vectors and their components at specific points. At the peak of the trajectory, the vertical component  $v_y$  is zero, and the velocity vector  $\vec{v}$  is purely horizontal, identical to  $v_x$ .

**FIGURE 3.10** Graph of a parabolic trajectory with the velocity vector and its Cartesian components shown at constant time intervals.

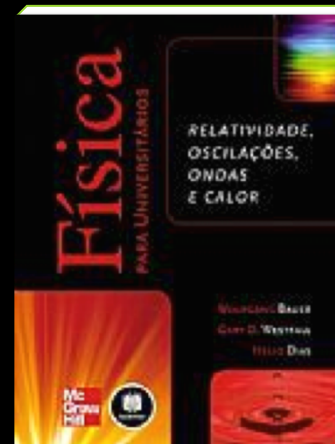
 **Velocity Components**

Although the vertical component of the velocity vector is equal to zero at the top of the trajectory, the gravitational acceleration has the same constant value as on any other part of the trajectory. Beware of the common misconception that the gravitational acceleration is equal to zero at the top of the trajectory. The gravitational acceleration has the same constant value everywhere along the trajectory.

 **Concept-Check 3.3**

Finally, let's explore the functional dependence of the absolute value of the velocity vector on time and/or the  $y$ -coordinate. We start with the dependence of  $|\vec{v}|$  on  $y$ . We use the fact that the absolute value of a vector is given as the square root of the sum of the squares of the components. Then we use kinematical [equation 3.12](#) for the  $x$ -component and kinematical [equation 3.17](#) for the  $y$ -component. We obtain

# PORTUGUESE VERSION



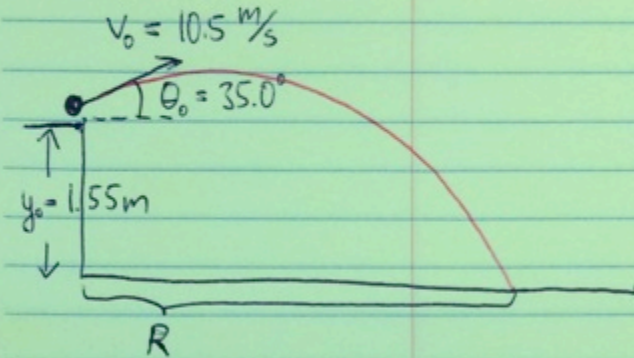
# TRAJECTORIES

## ► Problem solving

- Work with pencil and paper
- Peer graded evaluations

## ► Example

3.99. For a Science Olympiad competition, a group of middle school students build a trebuchet that can fire a tennis ball from a height of 1.55 m above the ground with a speed of 10.5 m/s and initial angle of  $35.0^\circ$  above the horizontal. What horizontal distance will the tennis ball cover before it hits the ground?



$$R = v_{x0} \cdot t = v_0 \cdot \cos \theta_0 \cdot t$$

$$y = y_0 + v_{y0} t - \frac{1}{2} g t^2 = 0$$

quadratic equation!

$$\Rightarrow t = \frac{1}{g} \left( v_{y0} \pm \sqrt{v_{y0}^2 + 2 g y_0} \right)$$

$$v_{y0} = v_0 \sin \theta_0 =$$

Only + sign for  $\uparrow$  is relevant, because ball cannot land before it is released  $t > 0$

$$\Rightarrow R = \frac{v_0}{g} \cos \theta_0 \left( v_0 \sin \theta_0 + \sqrt{v_0^2 \sin^2 \theta_0 + 2 g y_0} \right)$$

$$= 12.4 \text{ m}$$



# ELECTRONIC HOMEWORK

- ▶ Computer graded
- ▶ Randomized problems are different for every student (reduced copying and cheating)
- ▶ Immediate student feedback

The screenshot shows a web browser window titled "LON-CAPA Construction Space". The address bar displays the URL "educog.com/priv/BauerWestfall/2ndEdition/Chapter03/V0". The browser's toolbar includes navigation buttons, a search icon, and a "Reader" button. Below the toolbar, there is a navigation bar with links: "Wolfgang Bauer (Co-Author) Bauer Westfall Physics", "New Messages", "Roles", "Help", and "Logout". A green navigation bar contains links: "Main Menu", "Construction Space", and "Browse". The main content area displays a physics problem: "At the Science Olympiad competition, a group of middle school students use a trebuchet that launches a tennis ball from a height of 1.169 m above the ground with a speed of 14.81 m/s and initial angle of 37.97° with respect to the horizontal. What horizontal distance will the tennis ball cover before it hits the ground?". Below the problem, the answer "2.310x10<sup>1</sup> m" is shown in a green box. A green arrow labeled "Input Field" points to this box. Below the answer, a green box contains the text "You are correct." followed by "Previous Tries". A green arrow labeled "Submit Button" points to the "Previous Tries" link. At the bottom of the window, the text "Activated Editfields" is visible.

Input Field

Submit Button

NEWS: CourseWeaver Inc. Acquires EduCog, LLC | Feb 5

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HOMEPAGE PRODUCTS INITIATIVE ABOUT CONTACT

## CourseWeaver

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The diagram illustrates the CourseWeaver system as a central hub connecting various educational technologies. The components shown are:

- Authoring System
- Course Maker
- Autho Micro Payment
- e-Text
- Content Marketplace
- Education Learning Management System
- Testing Services
- e-Course Packs

# AVAILABLE IN BRAZIL

- ▶ Course management system: LON-CAPA, now CourseWeaver
- ▶ Portuguese version of course management system available
- ▶ Partnership with Science Club



# MULTI-VERSION EXERCISES

**3.99** For a Science Olympiad competition, a group of middle school students build a trebuchet that can fire a tennis ball from a height of 1.55 m with a velocity of 10.5 m/s and a launch angle of  $35.0^\circ$  above the horizontal. What horizontal distance will the tennis ball travel before it hits the ground?

**3.100** For a Science Olympiad competition, a group of middle school students build a trebuchet that can fire a tennis ball from a height of 1.55 m with a velocity of 10.5 m/s and a launch angle of  $35.0^\circ$  above the horizontal. What is the  $x$ -component of the velocity of the tennis ball just before it hits the ground?

**3.101** For a Science Olympiad competition, a group of middle school students build a trebuchet that can fire a tennis ball from a height of 1.55 m with a velocity of 10.5 m/s and a launch angle of  $35.0^\circ$  above the horizontal. What is the  $y$ -component of the velocity of the tennis ball just before it hits the ground?

**3.102** For a Science Olympiad competition, a group of middle school students build a trebuchet that can fire a tennis ball from a height of 1.55 m with a velocity of 10.5 m/s and a launch angle of  $35.0^\circ$  above the horizontal. What is the speed of the tennis ball just before it hits the ground?

## Multiple Versions for

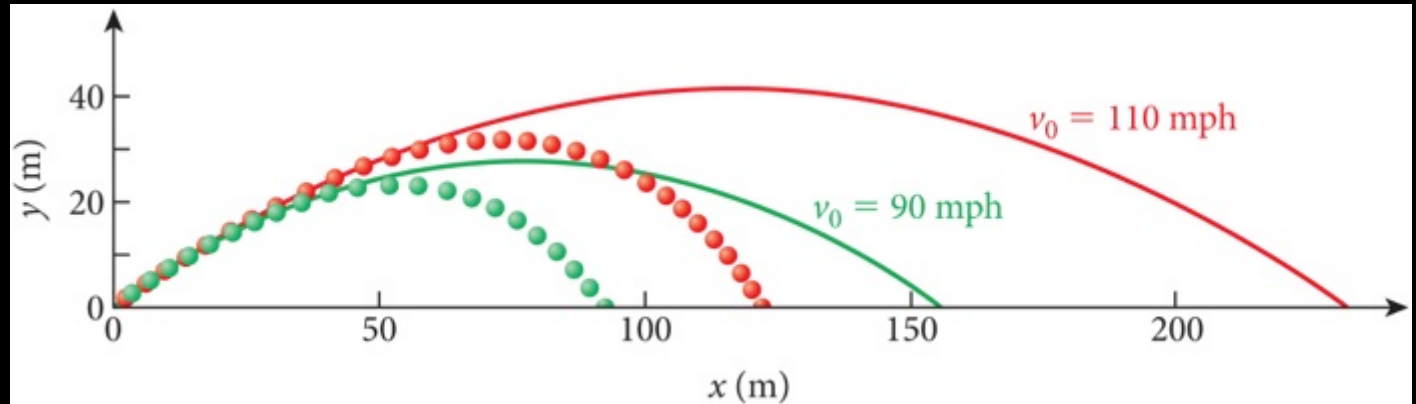
- Lecture
- Homework
- Quiz
- Midterm Exams
- Final Exam



# TRAJECTORIES

## ► Real-world complications

- Air resistance
- Spin
- ...



## ► Solve numerically

- Teach programming language (Python, html5, java, MatLab, Mathematica, FORTRAN, C, C++, ...)
- Programming tasks
- Numerical analysis

# TRAJECTORIES

## ► Computational task (4<sup>th</sup> Order Runge-Kutta)

```
*                                     ! First Step
      DO i = 1,n
        YT(i) = Y(i) + h/2*dYdt(i)
      END DO

*                                     ! Second Step
      CALL Derivs(n,t+h/2,YT,DYT)
      DO i = 1,n
        YT(i) = Y(i) + h/2*DYT(i)
      END DO

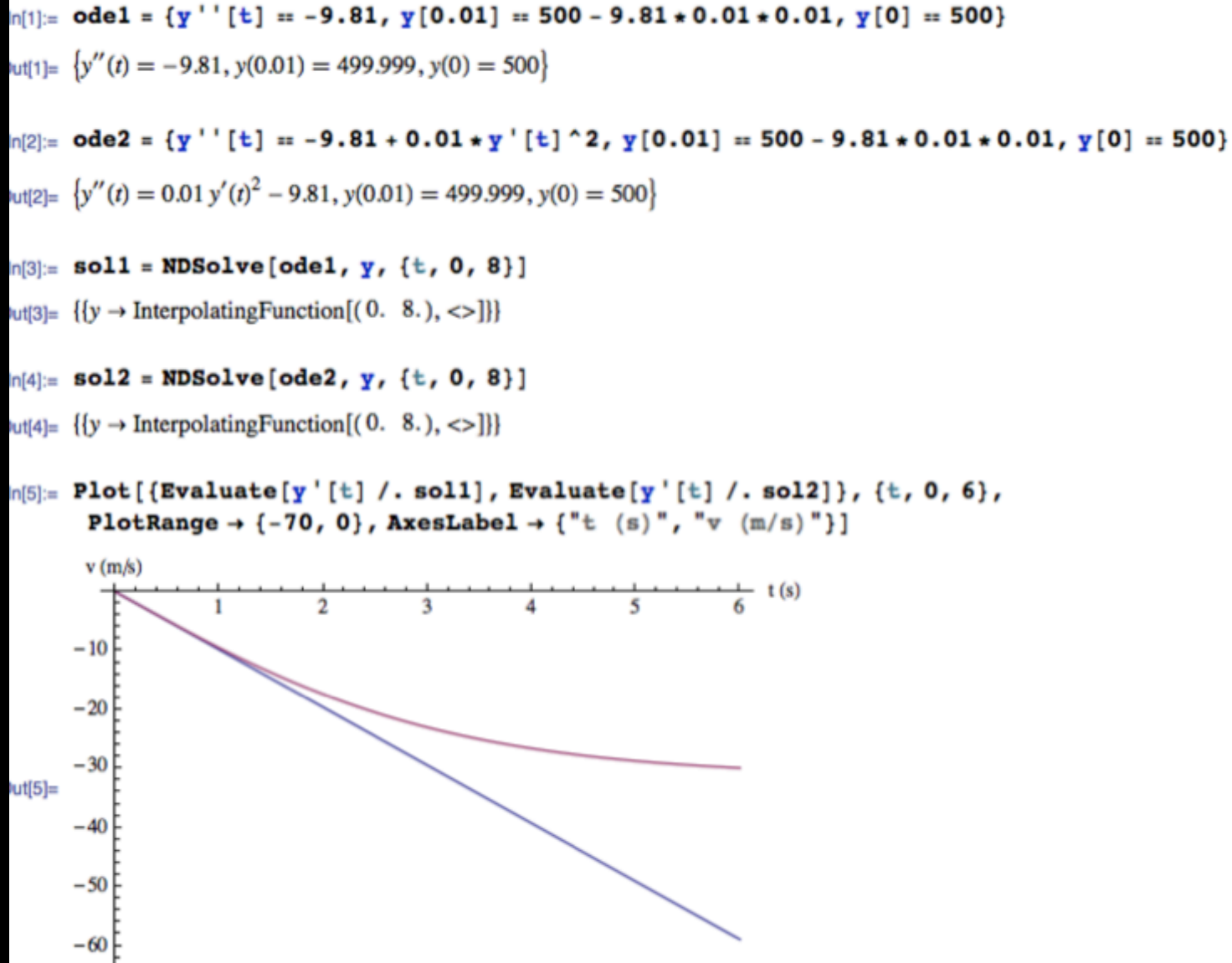
*                                     ! Third Step
      CALL Derivs(n,t+h/2,YT,DYM)
      DO i = 1,n
        YT(i) = Y(i) + h*DYM(i)
        DYM(i) = DYT(i) + DYM(i)
      END DO

*                                     ! Fourth Step
      CALL Derivs(n,t+h,YT,DYT)

*                                     ! Calculate Y(t+h)
      DO i = 1,n
        Y(i) = Y(i) + h/6*(dYdt(i)+DYT(i)+2.*DYM(i))
      END DO
```

# VISUALIZATION → INSIGHT

Here:  
Terminal  
Speed in  
Free-Fall  
with Air  
Resistance



# ADVANCED SKILLS

- ▶ Analyze real-world situations
  - ▶ Example: Analyze footage from sports videos
- ▶ Compare theoretical and computational findings to experimental situations
  - ▶ Integrated laboratory experiences
- ▶ Solve real-world engineering tasks
  - ▶ Design structures and devices
  - ▶ Design performance tests
  - ▶ Conduct performance evaluations



# EXAMPLE: BASEBALL



# EXAMPLE: BASEBALL



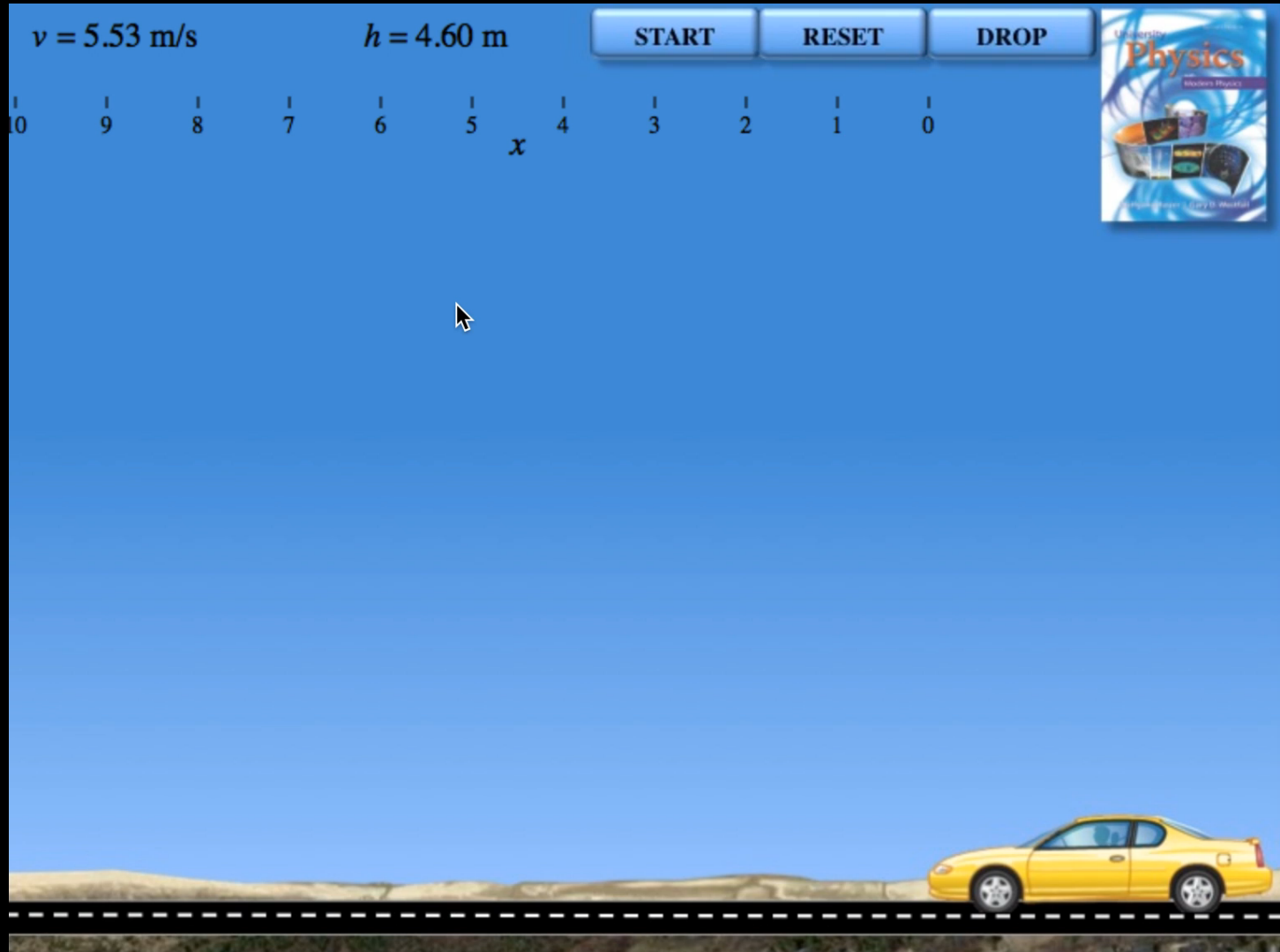
# EXAMPLE: BASEBALL

## Video Analysis: Impulse and Momentum Transfer





# FUN/GAMING INTEGRATION





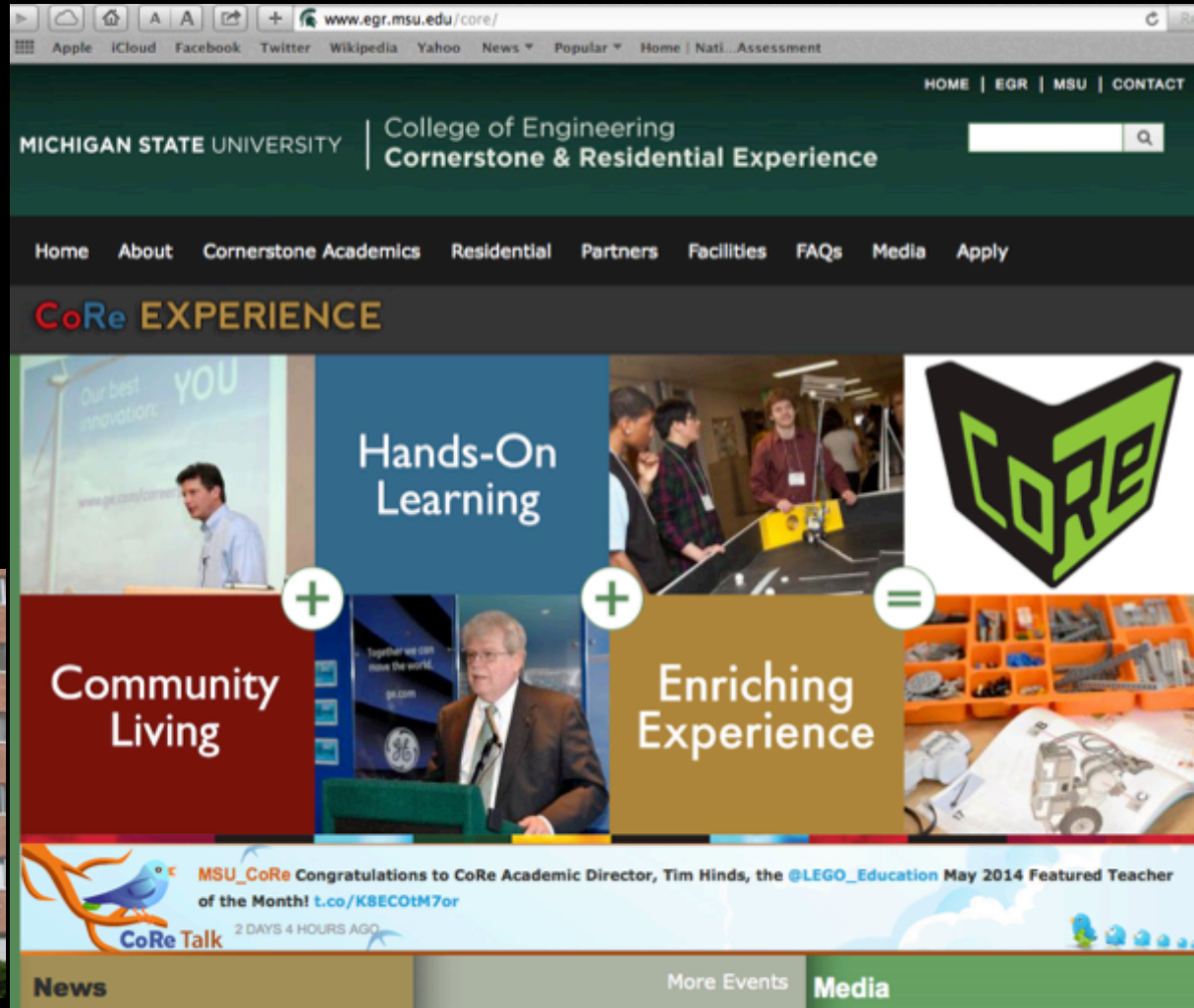
# PHYSICAL SPACE

## ► SCALE-UP style collaborative classrooms



# CORNERSTONE AND RESIDENTIAL EXPERIENCE

- ▶ Integration of first year academic experience with engineering living-learning community
- ▶ 'building the whole engineer'



www.egr.msu.edu/core/

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Community Living

Enriching Experience

MSU\_CoRe Congratulations to CoRe Academic Director, Tim Hinds, the @LEGO\_Education May 2014 Featured Teacher of the Month! [t.co/K8EC0tM7or](https://t.co/K8EC0tM7or)

CoRe Talk 2 DAYS 4 HOURS AGO

News More Events Media

# SUMMARY: FYIE

- ▶ First Year Integrated Engineering
- ▶ Tightly integrated interdisciplinary curriculum
  - ▶ Mathematics
  - ▶ Physics
  - ▶ Computer Science
- ▶ Problem-Based Learning
- ▶ Flipped classroom
- ▶ New student experience
  - ▶ Work in collaborative teams
  - ▶ Cohort formation