What are we going to learn in this class?

A summary of the goals and objectives for P131

Course goals

These are the fundamental goals that I would hope that you will take away from this course years from now! They are divided into three categories: Physics Goals, Skills Goals, and Team Goals.

Physics Goals

These are the basic goals of any introductory physics course and are deeply connected to the material we will be covering

1. **Physics is a list of principles and the fundamental ideas that relate them, NOT a list of equations…** This is quite possibly the most common misconception that people have about physics: they tend to think of physics as a list of formulae to be memorized and that all solving physics problems entails is finding the correct formula to get from where you are to where you want to be. This could not be further from the truth. Physics is a list of conceptual ideas expressed mathematically. These conceptual ideas form the "rules" that all of the other sciences, biology, chemistry, etc., have to follow. Thus, knowing the basic principles of physics is beneficial to any scientist!

2. **These principles can be expressed in multiple different ways…** When people think of physics they tend to think of equations. However, the ideas of physics can be represented in words (as was done in Europe in the days before Isaac Newton!) pictures, and graphs. As a budding scientist, it is important for you to be able to think of ideas in multiple formats and to be able to decide which format is the best for a given situation.

3. **Appreciate the value of the problem solving method used by the discipline of physics…** This is the goal most commonly given by non-physics faculty as to why they want their students to take physics, "problem solving." However, the problem solving method used by physicists is a bit different than that to which you may be accustomed. In physics, we reason from the fundamental principles at play in a given situation. This requires you to look beyond the surface features in a given problem to see how a person throwing a ball, a block sliding down a ramp, and a building standing still are all similar in that they all rely on the same fundamental principle of $\sum \vec{F} = m\vec{a}$. As a consequence of starting from fundamental principles, we physicists like to employ what is known as a "reductionist" approach and think about an idealized world first. This idealized world can seem quite bizarre to people new to physics as it is populated with point masses moving across frictionless surfaces. The goal of this approach is to move to a problem where the fundamental principles are easier to see and understand. The complications that are present in the real world are then added back in later.

4. **Learn how to use fundamental principles to generalize from one specific situation to a class of similar ones…** Often, we will study a particular principle or idea within the context of a

specific situation. The beauty of the laws of physics, however, is that these laws can be applied anywhere and the results of one analysis can often be applied to other related problems. For example, the motion of ANY object near the surface of the earth shares certain features. Thus, by studying the motion of a basketball, you can infer something about a skydiver. The trick is knowing what aspects of a given problem transfer to a new situation and which do not – your guide here are the fundamental principles (see Physics Goal #1).

5. **Understand that the physics we study is connected to your everyday experience and the material in your other courses…** We want you to see the applications of physics all around you and to connect to your other courses. As such, we may ask you to pull information from your everyday experience or other knowledge to solve problems. Our hope is that physics will provide a new perspective on the material in your other classes.

Skills Goals

In addition to physics content, there is a certain set of skills that we want you to take away from this class.

1. **Understanding measurement…** We want you to understand that data are noisy – you never measure the same value twice. This fact informs the way scientists should report and interpret numerical data.

2. **Become proficient with a set of mathematical tools to model the world and solve problems…** Math isn't magic. In this course we want you to learn a set of tools that are commonly used by scientists in every field as all fields become ever more quantitative. These tools include estimation, simulation, vectors, trigonometry, and the ability to work in symbols.

3. **Learn how to learn technical subjects independently…** Most of you are scientific/technical/medical tracked. In all of these fields, you will need to be able to learn technical material on your own to stay up-to-date with the latest research in your field. This is a skill like any other that takes practice. The team-based-learning (TBL) environment of this course provides a great opportunity to practice this skill where you have support. In this class, *you* are responsible for using the tools provided to achieve a basic level understanding of the content *before you come to class*. We will show you skills and techniques to learn how to do this throughout the semester.

Team goals

This is a team-based-learning class. As such your performance as a team is very important. You will be using your team to deepen your understanding of the concepts in this class. Similarly, your team will be relying on you to contribute.

1. **Appreciate that the "solitary genius" image of a scientist which is so pervasive in our culture no longer exists (if they ever did)…** Science, all science, is now done in teams ranging in size from small teams of three to massive collaborations with memberships in the thousands. These skills are something you can put on your CV/Resume as having developed in this class!

2. **Appreciate that the work done by a team is usually better than the product of even its strongest member….** You will see over the course of the semester that this is true!

Unit-by-unit goals and objectives

This course is divided into five units, each two-to-three weeks long. What follows is a short description of each unit: the key topics are listed as well as a set of objectives that you should be able to accomplish by the end of the unit. The course goals to which these objectives correspond is indicated by a code in parentheses, e.g. (PG1) means that the objective corresponds to Physics Goal #1.

Mathematical Tools and Foundational Concepts

In this unit, we will explore some of the fundamental mathematical tools and basic concepts that we will need in our study of physics

<u>Topics and Objectives</u>
By the end of this unit, students should be able to…

Units
- Convert complex units (SG2)
- Convert units of dimension greater than one ($cm^3 \leftrightarrow m^3$ for example) and explain why the conversion works the way it does (SG2)
- Be able to calculate the density of any fluid (PG1)

Problem solving
- Describe the benefit of estimation in solving problems (PG3)
- Know some basic scales for length, mass, and time (PG3)
- Use their everyday knowledge and personal scales to solve a variety of complex problems to one significant digit (PG3)
- Evaluate the benefits and limitations of the point-mass approximation (PG3)
- Describe the properties of the ideal liquid (PG3)
- Evaluate the benefits and limitations of the ideal liquid (PG3)

Understanding properties of data
- Know the definition of mean and standard deviation and be able to calculate these quantities for any data set (SG1)
- Use the idea of standard deviation to estimate the number of appropriate digits for any calculation (SG1)
- Know that error bars on a graph represent standard deviations (SG1)
- Qualitatively incorporate standard deviations into interpreting graphs (SG1)

Coordinate Systems
- Define what a coordinate system is (SG2)
- State the impact of coordinate system on the solution to a problem (SG2)
- Be able to establish a coordinate system for any problem (SG2)

Vectors
- Know that a vector is a quantity with magnitude and direction (SG2)
- Convert between magnitude/direction and component form for any vector (SG2)
- Describe both visually and mathematically what happens when a scalar is multiplied by a vector (SG2, PG1)
- Add vectors by components (SG2)
- Given two graphical representations of vectors, be able to draw the sum or difference (SG2, PG2)
- Use graphical vector addition to solve a problem (SG2, PG2, PG3)

Position
- Describe how position is different from distance (PG1)
- Determine which to use in a given problem (PG3)
- Identify that position is a vector (PG1)

Velocity
- Describe how velocity is different from speed (PG1)
- Identify that velocity is a vector (PG1)
- Identify that velocity is always parallel to the path (PG1)
- Use the relationship between average velocity and position to solve problems on the motion of objects (PG3)
- Given a velocity as a function of time, be able to solve for the position as a function of time using simulation (PG3, SG2)

Acceleration
- Identify that acceleration is a vector (PG1)
- Given an acceleration, be able to describe how velocity will change (PG2, PG3)
- Given how velocity is changing, be able to determine the sign of acceleration (PG2, PG3)
- Give an example of a case where acceleration is not parallel to path (PG5)
- Give an example of a case where velocity is zero and acceleration is not (PG5)
- Give an example of a case where acceleration and velocity are in opposite directions (PG5)
- Solve for the velocity of an object as a function of time algebraically in the case of constant acceleration in one and two-dimensions (PG3, SG2)
- Solve for the velocity of an object as a function of time using simulation for any acceleration as a function of time in one and two-dimensions (PG3, SG2)

Graphs
- Describe the units of the value, slope, and integral of any graph (SG2)
- Use the slope of a position vs. time graph to sketch a velocity vs. time graph (PG2)
- Use the slope of a velocity vs. time graph to sketch an acceleration vs. time graph (PG2)
- Use the area under an acceleration vs. time graph to sketch a velocity vs. time graph (PG2)
- Use the area under a velocity vs. time graph to sketch a position vs. time graph (PG2)
- Be able to draw a qualitatively correct position vs. time graph from a written description of an objects motion in one and two-dimensions (PG2)
- Be able to give a written description of an objects motion from a position vs. time graph (PG2)

Newton's Laws and Forces

In this unit we will discuss a set of ideas which is central to the study of physics: Newton's Laws. Newton's Laws describe how *forces* interact with objects to cause/influence their motion.

Topics and Objectives
By the end of this unit, students should be able to…

Object Egoism
- Define the idea of object egoism (PG1)
- Identify which forces are acting on any given object at any given instant (PG1)
- Represent these forces in terms of free-body-diagrams (PG2)

- Recognize the use of free-body-diagrams in determining the sum of forces acting on an object (PG2, PG3)

Newton's Laws
- Explain Newton's Laws in their own words (PG1, PG2)
- Apply Newton's Laws to determine the acceleration of an object at any given instant (PG1)
- Given a net acceleration, be able to predict the direction of the net force acting on an object (PG1)
- Qualitatively predict the motion of an object acting under a net force (PG1)
- Determine the constraints on the motion of an object, e.g. if two objects are connected by a string, they must accelerate at the same rate, and use the constraints to solve for the motion of an object acted on by forces (PG3)
- Use simulation to determine the motion of an object acted on by a force (SG2)

Fields and the forces normal, tension, spring, flat-earth-gravity/weight, friction, buoyancy, drag and viscosity
- Explain the origin of each force in physical terms (PG1, PG2)
- Evaluate descriptions of origins (PG2)
- Calculate the magnitude of each force under a variety of circumstances (PG1, PG2)
- Explain gravitational interactions in terms of the gravitational field $\vec{g}$ (PG1)
- Describe when flat-earth-gravity is a valid approximation (PG3)
- Categorize these forces as contact/non-contact, fundamental/constraint/experimental (PG1)
- Contrast fundamental forces, constraint forces, and force laws arising from data (PG1)
- Construct a mathematical model of an experimental force law from data (SG1, SG2)
- Assess the benefits and limitations of experimental force laws (SG2, PG3)
- From simulation of the motion of one object moving under flat-earth gravity, predict the motion of other objects moving in flat-earth gravity, both with and without air resistance (PG4, SG2)
- From simulation of the motion of one object moving under the impact of a spring, predict properties of the motion of other objects attached to springs (PG4, SG4)

Graphs
- Construct a verbal description of the motion of an object based upon a force vs. time graph and some knowledge of Newton's Laws. (PG2)

Forces and…

In this unit, we will think about forces in conjunction with some other quantity to get impulse, torque, work, and pressure. Along the way, we will introduce three more fundamental concepts: momentum, kinetic energy, and center of mass.

Topics and Objectives
By the end of this unit, students should be able to…

Center of mass
- Construct a definition of center of mass that contains all of its attributes (PG1)
- Design a procedure to measure center of mass (SG1)

Torque – A force applied at a particular place
- Calculate the net torque exerted by any force on any object including sign (PG1)
- Describe how to get the maximum torque on an object for a given force (PG1)
- Contrast force and torque (PG1)

- Identify the net torque and net force acting on an object at rest PG1)
- Solve for unknown forces in equilibrium problems (PG3)
- Choose an efficient axis of rotation for any equilibrium problem (PG3)

Impulse – A force applied for some amount of time
- Calculate the momentum for any object (PG1)
- Calculate the impulse for any force acting for some given time (PG1)
- Recall that momentum is a vector (PG1)
- From the change in momentum, compute the average force (PG1)
- From an impulse, compute the change in momentum (PG1)
- Identify which aspect of an F(t) graph represents impulse (PG2)
- Compute the net change in momentum of an object using an F(t) graph (PG2)

Pressure – A force applied over some area
- Define a fluid element (PG1)
- Compute the pressure for a given area (PG1)
- Apply Newton's 2nd Law to a fluid element to determine the pressure as a function of depth and use this result to make predictions and solve problems (PG1, PG4)

Work – A force applied for some distance (or pressure resulting in a change in volume)
- Compute the kinetic energy for a given object (PG1)
- Compute the work done by a given force on any object given a force and distance (PG1)
- Compute the net work done from the initial and final velocities (PG1)
- Compare and contrast the units for work and torque (PG1)
- Compare the units of force times distance and pressure times volume (PG1)
- Compute the work done by a pressure resulting in a change in volume (PG1)

Conservation Laws

In this unit, we will be exploring the idea that some quantities are *conserved*, an idea which is very central to a modern perspective of physics.

Topics and Objectives
By the end of this unit, students should be able to…

Momentum
- Recall that momentum is conserved (PG1)
- Apply conservation of momentum in one and two-dimensions to solve collision problems (PG3)

Energy
- Define energy as the ability to do work (PG1)
- Define conservative force (PG1)
- Determine if a given force is conservative or not (PG1)
- Know that only conservative forces have potential energies associated with them (PG1)
- Calculate the potential energy of a system including gravitational and/or spring forces (PG1, PG2)
- Solve problems using conservation of energy including problems with non-conservative forces (PG3)
- Solve problems using both conservation of energy and conservation of momentum (PG3)
- Explain, in terms of energy, what must happen to an object if work is done on it (PG1, PG2)

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Thermodynamics and statistical mechanics

In this unit we are going to connect the big ideas we have discussed thus far with the microscopic scale that you may have studied in a chemistry class. Hopefully, this will provide a more thorough understanding of some of the ideas that you have learned in other courses. The big new idea will be entropy. You have probably encountered it in a chemistry class, but here we will talk about the modern definition.

Topics and objectives
By the end of this unit, students should be able to…

Mole
- Define the mol as a unit (PG1)
- Compute the number of mols given the number of particles and vice versa (PG1)

Ideal gas
- List the properties of the ideal gas approximation (PG1)
- Apply the ideal gas law (PG1)
- Translate the nR form of the ideal gas law into the Nk form (PG2)
- Discuss the connection between the ideal gas law and the idea of conservation of energy (PG2)

Basic thermodynamic quantities and the First Law of Thermodynamics
- Define heat as a transfer of energy through the random motion of molecules (PG5)
- Define temperature in terms of average kinetic energy (PG1 & PG5)
- Apply the definition of temperature in terms of average kinetic energy to find the average speed of molecules (PG1)
- Explain how an object could feel cold but have a high temperature and provide an example (PG1 & PG2)
- Predict the temperature change of an ideal gas undergoing free expansion and explain in terms of average kinetic energy (PG4)
- Define the equipartition theorem (PG1)
- Determine the number of degrees of freedom for a given molecule (PG1)
- Define specific heat (PG1)
- Apply $Q = nC_V\Delta T$ (PG1)
- Recall that the specific heat is different for constant pressure (PG4)
- Predict the specific heat of at constant volume for an ideal gas or solid in any number of dimensions (PG4)
- List a couple of different kinds of internal energy (PG1)
- Write down the conservation of energy in terms of internal energy, heat, and work (PG1)
- Indicate whether energy is entering or leaving the system based upon the sign of heat (PG3)
- Indicate whether energy is entering or leaving the system based upon the sign of work (PG3)
- Explain why a free compression does not violate the First Law of Thermodynamics (PG3)

Second Law of Thermodynamics
- State the Second Law of Thermodynamics (PG1)

- Describe the compatibility of the Second Law of Thermodynamics and the Theory of Evolution (PG5)
- Define microstate and macrostate (PG1)
- Count the number of microstates for a collection of small discrete objects such as coins, dice, cards, etc. (PG1)
- Manipulate logarithms (SG2)
- Calculate the number of possible ways to distribute N objects into n categories (SG2)
- Use the Stirling approximation to find $\ln(N!)$ (SG2)
- Calculate the entropy of a collection of small discrete objects (PG3)
- Calculate the probability of a free compression (PG4)
- Compare and contrast the definition of entropy in terms of microstates vs. "disorder" (PG1)
- Compose a formulation of the Second Law of Thermodynamics in terms of the microstate definition of entropy (PG1, PG4, and PG5)

Additional objectives for themes that run throughout the course

By the end of the course, students should be able to…

Problem solving
- Choose which fundamental principles: kinematics, Newton's Laws, conservation of energy, etc. may be needed for any given problem (PG3)
- Plan the steps for a solution before proceeding (PG3)
- Evaluate the merits of two equally valid solutions (PG3)
- Estimate quantities in various SI units (get a feel for the units) (PG5)
- Be able to solve problems in symbols (SG2)

Learning how to learn technical subjects
- Construct a map connecting different quantities (SG3)
- Compose short paragraph(s) describing a given quantity (SG3)
- Compare the merits of expressing ideas in maps, paragraphs, and equations (SG3)
- Evaluate other maps and explanations (SG3)

Teams
- Evaluate performance of team-mates (TG1)
- Accurately evaluate their own contributions to teams (TG1)
- Compare the effectiveness of teams to the effectiveness of individuals (TG2)
- Practice working with others (TG1)
- Manage team work to achieve common objectives (TG1)