# Tutorial – Newton's $2^{nd}$ Law
**Instructor's Guide**

## Overview

This tutorial addresses the common "misconception" that motion requires force, e.g., the idea that an object moving upward must feel a net upward force. However, instead of treating that "misconception" as a completely wrong idea that must be replaced, the tutorial treats it as an idea that can become productive when refined in a certain way: A net force is needed to *initiate* (or change) motion but not to *maintain* motion. Epistemologically, the point of the tutorial is to help students see their common-sense ideas as something that can be usefully refined rather than as something that must be ignored in physics class.

Here's the overall flow. In section I, students consider a boy being pulled upward by a rope at steady speed, and come face to face with the contradiction between Newton's $2^{nd}$ law (upward force from rope equals downward force from gravity) and the common-sense idea that the rope's force must "beat" gravity. Then, in section II, the tutorial helps students make the distinction between *initiating* the boy's motion, during which there's an acceleration from $v = 0$ to the boy's steady speed, and *maintaining* the boy's motion, during which there's no acceleration. If all goes well, students will come to see that "motion requires force" needs to be refined to "a net nonzero force is needed to initiate (but not maintain) the boy's motion.

This tutorial can serve as an introduction to intuition refinement diagrams (part IIC), especially if you take some time not too long after this tutorial to go over the idea of refining intuitions.

**<u>I.</u>**
The key here is to make sure students *get* the contradiction between Newton's $2^{nd}$ law and the idea that the rope must beat gravity.
A.
There's no need for this to be a formal free-body diagram. In fact, forcing students to draw a formal free-body diagram may be counterproductive, contributing to their viewing FBDs as assignments rather than as sense-making tools. Just let them draw any diagram that they feel represents the given information usefully.
B.
Students may well answer this question incorrectly, usually with an answer like "The rope has to exert a force greater than 250 Newtons in order to overcome the 250-N gravitational force and move Timmy upward." This argument, while incorrect, is certainly intuitive for many students, and most come up with it spontaneously, either here or in part C. TAs should not argue with students here; the rest of the tutorial will address this "misconception."
C.

D.
We’ve observed that most groups converge on the right answer here.
E.
Many students are uncomfortable. They can see both sides of the argument (the rope force is greater than 250 N, and the rope force is equal to 250 N); both have good reasons behind them; and they can’t both be right. The point of the tutorial is to help students learn to deal productively with such situations.

**Checkpoint 1**
Make sure the students understand the Newton’s 2nd law reasoning and the intuitive reasoning. They should realize that there is a disagreement between these two. If a student *isn’t* uncomfortable at this point in the tutorial — for instance, if he’s just willing to accept what Newton’s 2nd law says and move on — then the TA should try to get him to articulate *why* he’s not uncomfortable, with the goal of initiating a discussion about the role of common sense in learning physics.

**II.**
Most students can answer all the questions in this section correctly. They’re meant to be intuitive, and most students find them to be so. However, we’ve observed wide variations in how well students get the *point* of these questions. That’s why it’s important to initiate discussions with students about their answers to parts C and D.
A.
Students need to see that their intuitive idea and Newton’s 2nd law agree for this stage of the motion.
B.
This series of questions should help the students distinguish between the two different stages of motion in this situation.

**Checkpoint 2**
TAs should check that students have answered all the questions in this section correctly, and try to make sure that all members of the group “get” the underlying reasoning. Part C and D of the next section will help students to reflect on how those answers bear on page 1, so TAs don’t need to help students with that here.

C.
An intuition refinement diagram consists of a raw intuition, usually vague and underspecified (as common-sense ideas often are!), connected to two or more refinements of the raw intuition. The refinements are more precise, formal statements, both of which capture the spirit behind the original raw intuition but in different ways. The idea behind having students consider these diagrams is to help them see their “misconception” not as a hopelessly wrong idea, but rather, as the incorrect refinement of a productive common-sense idea (the raw intuition). So here, it’s true that a net force is needed for Timmy’s motion — if that “need” refers only to the initiation, not the maintenance of that motion.
D.
This is an explicit epistemology question, which students are inclined not to take seriously unless this kind of reflection about is supported and rewarded throughout the

course.  We've found that, even when students blow off this kind of question on their own, the TA can start a rich discussion about the issue simply by asking the question directly.

Here's our dream response to this question: "To be convincing, it's not enough to justify the correct answer; we must also understand why other answers (which, after all, also seemed justified) are not correct.  So it's not enough to just cite Newton's laws and be done with it.  Instead, we have to look carefully at the intuitions that justified the alternative answers, and find the extent to which the arguments suggested by those intuitions hold up under scrutiny.  Usually there is quite a bit of truth in the intuitions. However, they often need refining, as illustrated in the intuition refinement diagram.  The point of part II is to examine and refine the intuitive arguments that compete with the conclusion dictated by Newton's laws."

– Students will probably not give such a complete answer, but will often articulate the first or second part.  A full-class discussion can help students hear other viewpoints.

**Checkpoint 3**

The TA should ask the students to discuss their answers to parts C & D.

**Tutorial Homework**

Students practice the new and difficult skill of reconciliation as they consider an object moving at constant speed with two forces acting on it.  This exercise reinforces the tutorial experience, in which apparently contradictory arguments are seen to be consistent once they are more carefully specified.  There is also a reflection question on the worth of examining one's mistakes.