



# Placing Constraints on Student Solutions as a way to develop Principle-Based Problem Solving

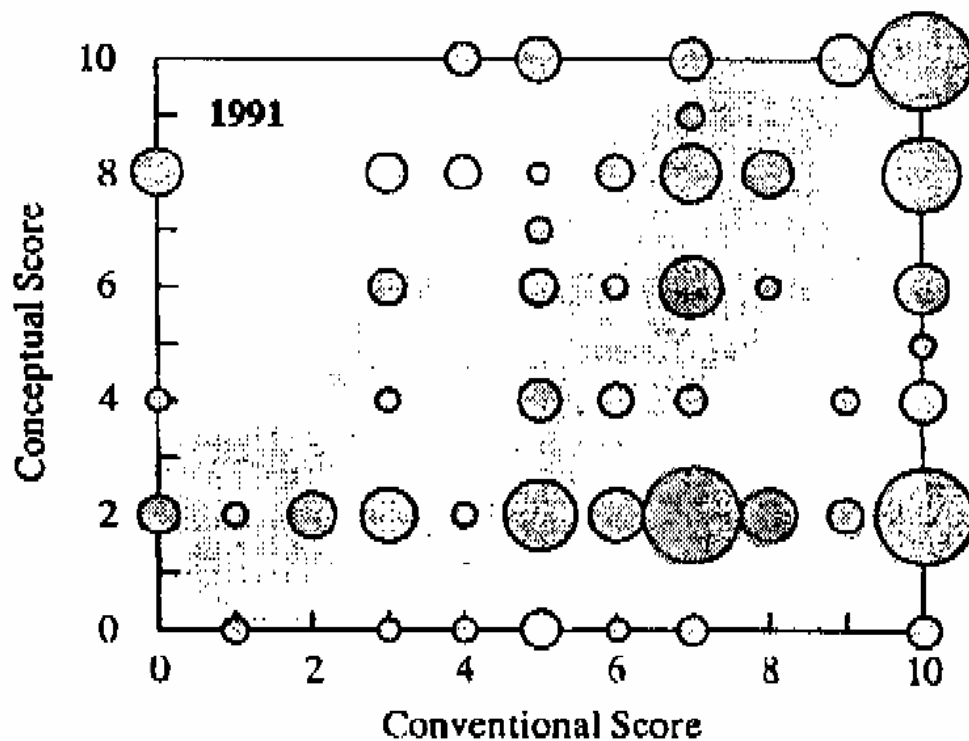
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# The Problem

- Introductory physics courses often result in students who use inappropriate problem solving strategies (i.e. rote memorization, plug & chug, equation hunting, etc.)
- Evidence of this is that traditionally-taught students often do better on conventional problems than their conceptual understanding should allow.\* **Students are not using physics principles to solve problems.**



\*Graph from Mazur (1997). Peer Instruction: A User's Manual.



# An Instructor's Choice of Constraints (Requirements) on Student Problem Solving Influences Student Learning

## Instruction

**Traditional instruction: minimal constraints**

## Problem Solution Process

**Undesirable Process**

Plug & Chug, rote memorization

## Problem Solution Product

**Undesirable Product**

Scribbled equations and a circled number at the end

**Problem-solving framework: process is constrained**

**Desirable Process**

Principle-based problem solving

**Desirable Product**

Logical solution

Highlights the process of problem solving as done by experts and constrains student problem solving to match this process.



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## Minnesota Model

(Heller & Heller)

1. Visualize the Problem
2. Physics Description
3. Plan a Solution
4. Execute the Plan
5. Check and Evaluate

## Overview, Case Study Physics

(VanHeuvelen)

1. Pictorial Representation
2. Physical Representation
3. Math Representation
4. Solution
5. Evaluation



# Many instructors are reluctant to put constraints on students' problem solving process

- Some believe that the problem-solving frameworks do not accurately represent the problem-solving process.
  - **“Problem solving involves trial and error.”**
  - **“Problem solving is an art form that is different for each problem.”**
- Some find problem-solving frameworks cumbersome and rigid.
  - **“It’s hard for me to solve the problem that way.”**
  - **“I wouldn’t have liked to do that when I was a student.”**
  - **“I don’t think I can get my students to do that.”**



# Would Instructors Be Willing to Put Constraints on Students' Products (i.e. Problem Solutions)?

## Instruction

## Problem Solution Process

## Problem Solution Product

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**Undesirable Process**  
Plug & Chug, rote memorization

**Undesirable Product**

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**Problem-solving framework: process is constrained**

**Desirable Process**  
Principle-based problem solving

**Desirable Product**

Logical solution

**product is constrained**

**Desirable Process?**  
Principle-based problem solving?

**Desirable Product**

Logical solution



# Physics Instructors are Familiar with Constraints on their Problem-Solving Product

An analogy: academic research and publishing

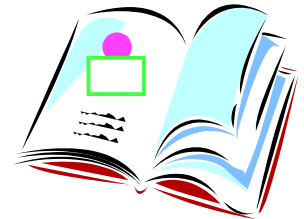
## Research Activity: Process



- Often non-linear
- Understanding develops during the process
- Different for each project
- Different for different researchers (experience, skills, prior knowledge)

## The Article: Product

- Usually linear
- Reflects a full understanding
- Most articles have a similar structure (e.g., introduction, review of prior research, research questions, etc.)





# Questions

1. Can an instructional design based on constraining the product (i.e. student solutions) produce students who are principle-based problem solvers?
2. Do instructors who object to constraining the problem-solving process find it acceptable to constrain the problem-solving product?

## Context

- **Western Michigan University**
  - ~30,000 Students (85% state residents, 75% acceptance rate)
- **Fall 2003**
- **2nd Semester Introductory Calculus-Based Physics**
  - ~70 Students (mainly engineering and science majors)
  - Mainly 2nd and 3rd year students
  - Daily whole-class meetings (50 min)
  - Weekly labs (2 hours)



# Instructional Design

Course Component	Purpose
• <b>Required Parts of a Problem Solution (constrain the product based on parts of an expert solution)</b>	Encourage expert problem solving strategies and avoid rewarding novice strategies.
• <b>Explicit identification of main ideas</b>	Help students develop a hierarchical knowledge structure.
• <b>Weekly Quiz or Exam with both conceptual questions and quantitative problems – all questions and problems are novel.</b>	Encourage students to focus their efforts on understanding rather than memorization.
• <b>Modeling of “expert” problem solving procedures (e.g., Heller &amp; Heller)</b>	Help students identify differences between expert and novice problem solving procedures
• <b>Cooperative Group Work (e.g., Heller &amp; Heller)</b>	Students exposed to alternative views and learn from one-another.
• <b>Interactive Lectures (e.g., Mazur, Meltzer)</b>	Discourage passive listening.
• <b>Students read text before class (e.g., Mazur and others)</b>	Allows for more effective use of lecture time.



# Required Parts of a Problem Solution\*

**Main Ideas** (What main ideas can be used to solve the problem?)

Criteria: Clearly Identified, Correct Type, Appropriate for Problem, Complete Set

**Justification** (Why are these main ideas appropriate?)

Criteria: Clear, Consistent with Main Ideas, Complete and self-consistent, Correct

**Procedure** (How can the main ideas be used to solve the problem?)

Criteria: Clear, Consistent with Main Ideas, Complete and self-consistent, Correct

**Implementation** (Use the procedure to solve the problem)

Criteria: Clear, Consistent with Procedure, Complete and Correct, Meaningful Evaluation

\*This is based largely on Leonard, Dufrense, & Mestre (1996). Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems.

AJP, 64 (12), pp. 1495-1503.



# Explicit Identification of Main Ideas

1. A charged particle exerts an electric force on another charged particle.

**Coulomb's Law**

$$(23) \quad \left| \vec{F}_{e_{1on2}} \right| = \left| \vec{F}_{e_{2on1}} \right| = k_e \frac{|q_1||q_2|}{r_{12}^2}$$

2. An electric field exerts an electric force on a charged particle.

**Definition of Electric Field (23)**

$$\vec{E} = \frac{\vec{F}_e}{q_o}$$

3. Charged particles produce electric fields.

**Electric field created by a charge distribution (23)**

$$\vec{E} = k_e \int \frac{dq}{r^2} \hat{r}$$

Special Cases

**Point Charge**  $\rightarrow E = k_e \frac{Q}{r^2}$

**Infinite, Uniformly Charged Line**  $\rightarrow E = 2k_e \frac{\lambda}{r}$

**Infinite, Uniformly Charged Plane**  $\rightarrow E = 2\pi k_e \sigma$



# Explicit Identification of Main Ideas

4. Charged particles have electric potential energy based on their position.
5. The electric potential is related to the electric field.
6. Capacitors store electric energy.
7. Moving charges are current.
8. Resistors impede the movement of charges.
9. In an electric circuit, energy is conserved around any loop and charge does not build up at any junction.
10. A magnetic field exerts a force on a moving charged particle.
11. Moving charges (currents) produce magnetic fields.
12. A changing magnetic flux creates an emf.
13. Inductors impede changes in current.
14. Accelerated charges produce electromagnetic radiation.



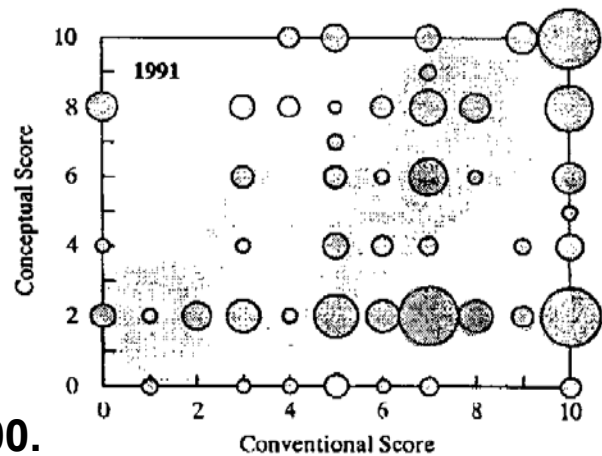
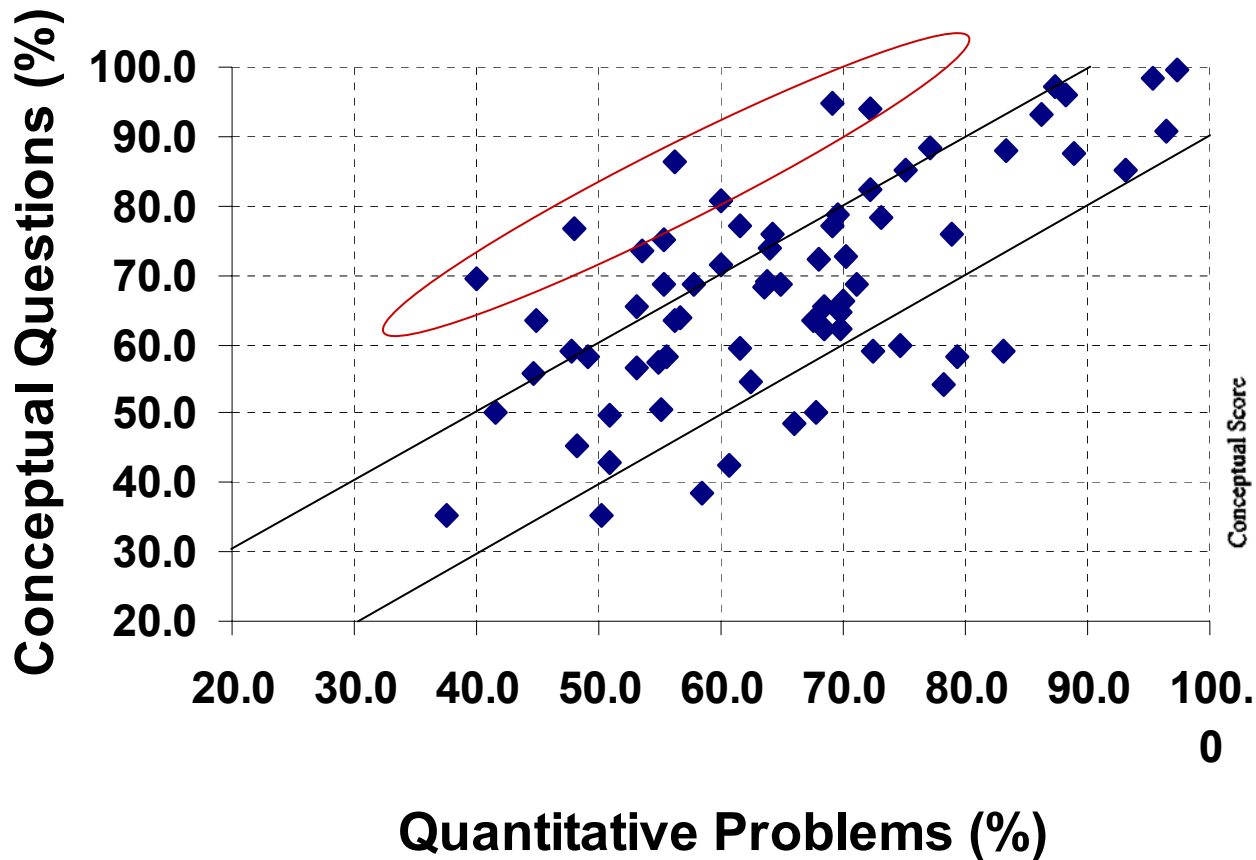
# **What Evidence is there that this instructional design encourages principle-based problem solving**

- 1. Students' performance on quantitative problems is correlated to their performance on conceptual questions.**
- 2. Students were generally successful in identifying the main ideas that are needed to solve a problem.**
- 3. Attrition for the course was lower than normal.**



# 1. Students' performance on quantitative problems is correlated to their performance on conceptual questions.

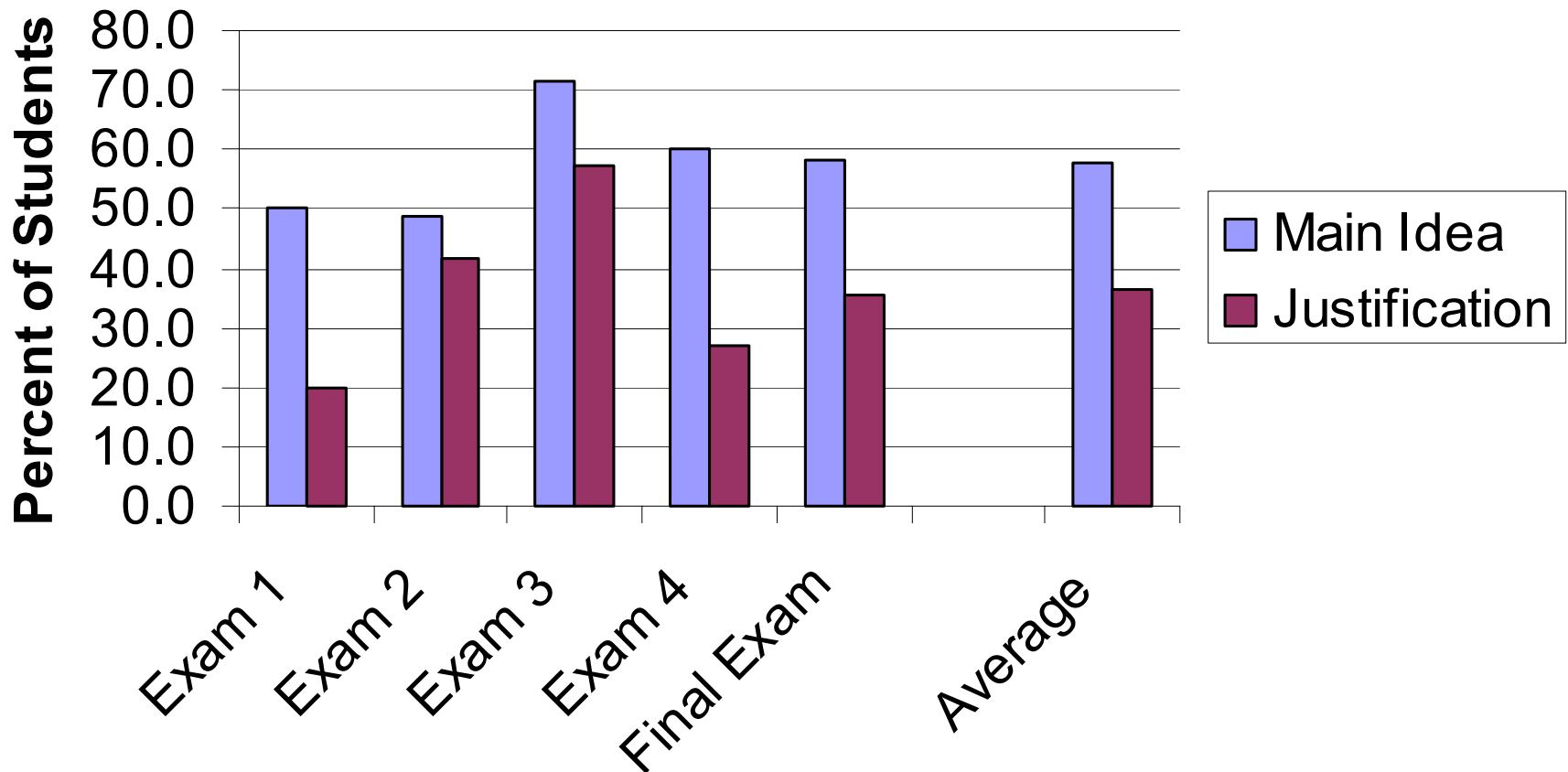
Data from all 4 exams and final exam. Correlation coefficient:  $r=.65$





## 2. Students were generally successful in identifying the main ideas that are needed to solve a problem.

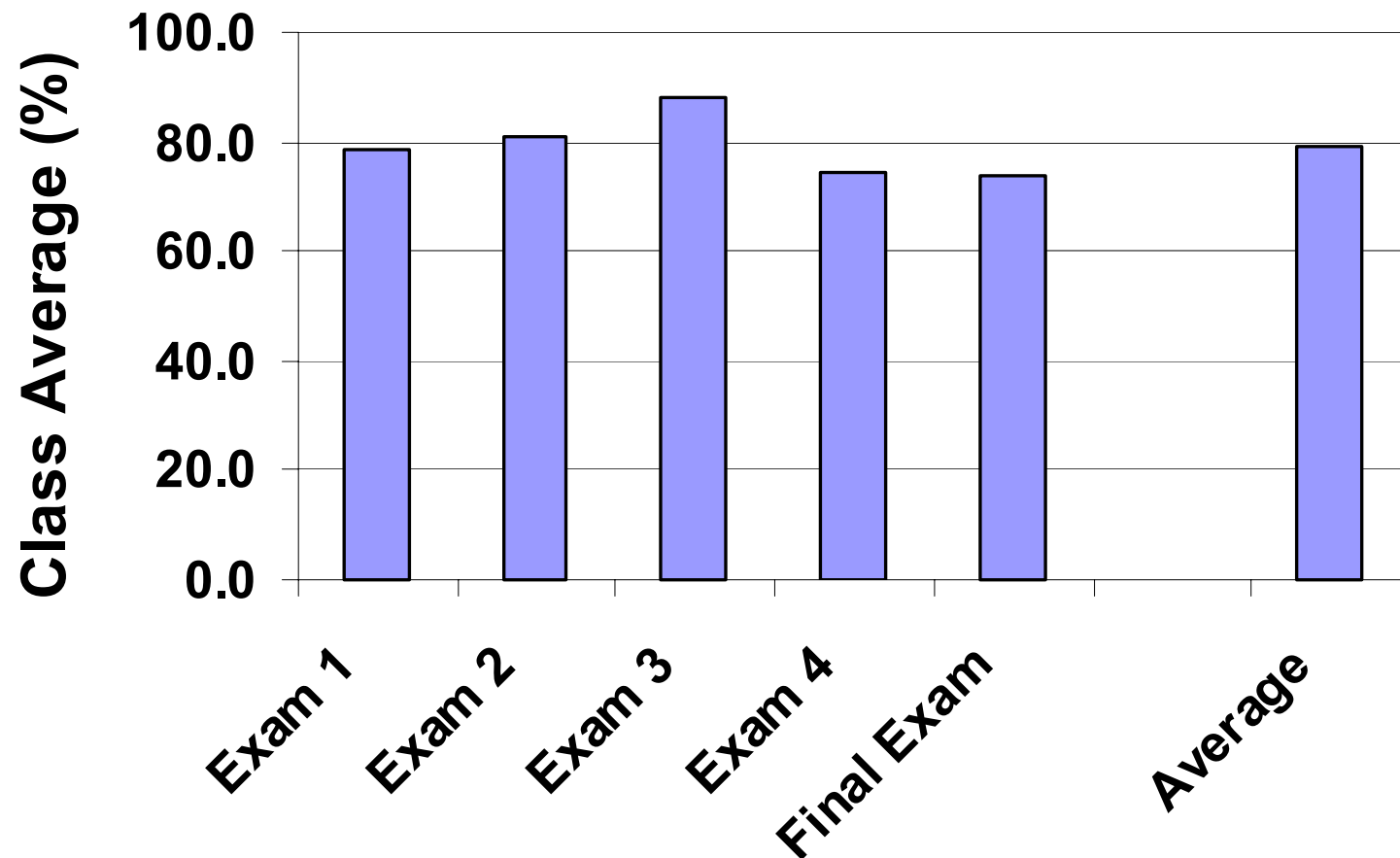
Percentage of students providing a completely correct set of Main Ideas and appropriate Justification.





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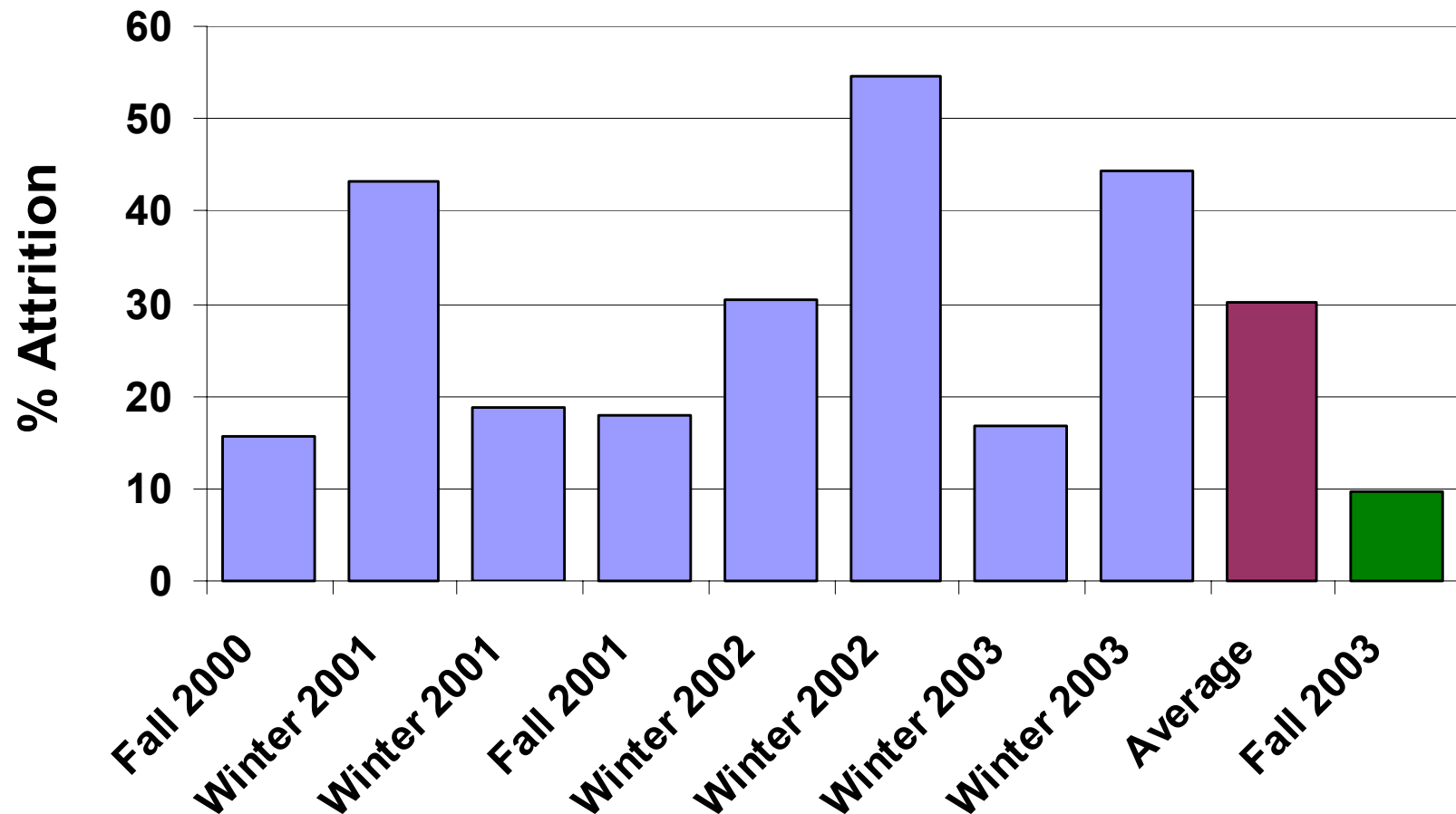
Scores (TA graded) on Main Ideas and Justification portion of exam problems during the semester.





### 3. Attrition for the course was lower than normal – the course makes sense to students.

**Attrition in Physics 207: Percent of students who start the semester and do not finish with a 'C' or better.**





# Preliminary Conclusions

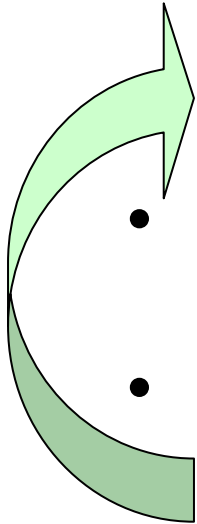
**There is evidence that an instructional design that places constraints on the product of student problem solving can result in students who use principle-based problem solving strategies.**

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# Next Steps

- Is it repeatable?
- **A colleague is using similar methods when teaching the course this semester.**
- Better measurement of student approaches to problem solving - are they really principle-based?
- Do instructors who object to constraining the problem-solving process find it acceptable to constrain the problem-solving product?





# The End

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