Mastery/self-paced introductory physics

Why we changed PHY 121 and PHY 122, and how mastery learning has taken root at UR.

Dan Watson

plus **Barbara Masi, Arie Bodek, Steve Manly,** and a cast of dozens

Department of Physics and Astronomy

> … I really liked your method of teaching physics. I felt that the unit exams allowed me to focus more in depth on each topic, helping me more fully to understand each topic. I hope they adopt your system during the year; best of luck with that.
>
> -- Mastery/self-paced PHY 113 student, *via* email to instructor Fred Moolekamp, Summer 2013.

Thanks for a great class. I really appreciated how in control and responsible I was for my own grade. I hope this system works out in the future, and it can eventually be translated into the regular semester.

-- Mastery/self-paced PHY 113 student, *via* email to instructor Fred Moolekamp, Summer 2013.

Outline

- Context and motives for changing PHY 121/122.
- Why mastery/self-paced instruction would help get more students through PHY 121/122.
- A brief introduction to the Personalized System of Instruction (PSI), a.k.a. Keller Plan – and relatives such as "flipped" classes.
- How students are currently advised, given the option of "classic" or mastery/self-paced PHY 121 and PHY 122.
- Bibliography of mastery/self-paced instruction: course design and controlled studies of the method's efficacy.

Issues in recent introductory physics courses for scientists and engineers

- Introductory physics classes have doubled in enrollment since the beginning of the recent 20% growth in UR's student body.
  - The increase continues, even though student-body growth is over.
  - Most of the increase: engineering majors.
- Growth has been accompanied by a disproportionately-large increase in students lacking adequate pre-physics skills.
  - Many still catching up to MTH 160s-level calculus.
  - Many more, with more fundamental gaps in their math background (algebra, geometry, trigonometry).

The Department of Physics and Astronomy is determined to help "save" as many of these students as possible.

Issues in recent introductory physics courses for scientists and engineers (continued)

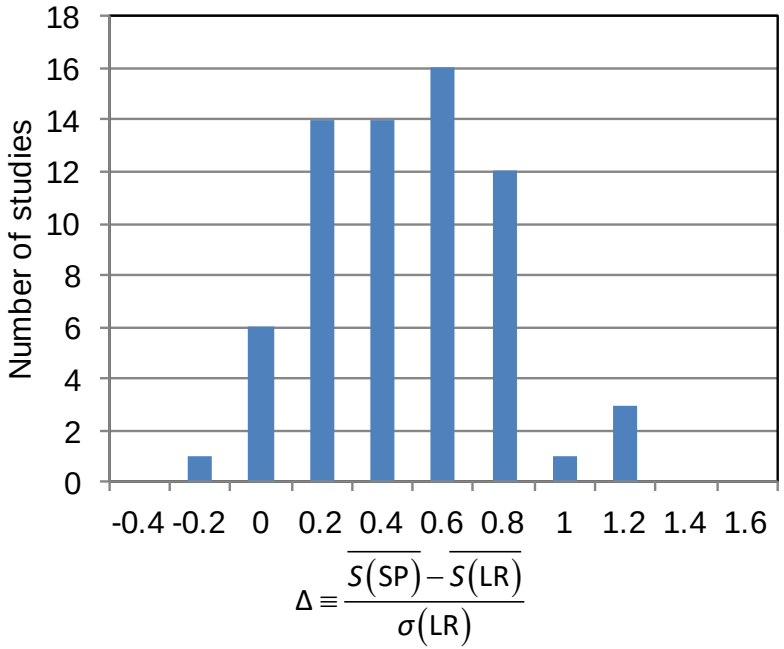
Our countermeasures:

- Split PHY 122 and PHY 121 into two independent lecture-workshop sections, as of Fall 2012.
  - Thus two faculty assigned to each of PHY 121/122.
  - The two independent classes still share labs.
- Increase in 1-1 tutoring, starting Spring 2012.
  - PAS tutors supported in part by Hajim School.
  - CETL, Kearns Center also adding tutoring resources.
- **One section offered mastery/self-paced (MSP): PHY 121P and PHY 122P, beginning in Spring 2014.**
  - PHY 121/122 (no P) will continue to be lecture-workshop format.

Why mastery/self-paced physics?

In PHY 121P and 122P we use the Personalized System of Instruction (PSI), better known as the Keller Plan. This mode has been used and tested widely, and is a good example of "evidence-based teaching." The advantages from our viewpoint:

- Compared to "forced-pace" lecture-recitation (LRE) courses covering the same material and taking the same final exam, **students in mastery/self-paced (MSP) courses perform better on the exams by an average of 0.48 standard deviations (σ).**
  - At right: results from 67 college classes (35 science/math, 32 social science).



Data: Kulik et al. 1990

Why mastery/self-paced physics? (continued)

- Final-exam score gains by MSP students over LRE students seem to be larger for those with worse preparation and/or lower aptitude, than those with good preparation and/or high aptitude.
  - Difference Δ, in standard deviations: $\Delta = \left[\overline{S(\mathrm{SP})} - \overline{S(\mathrm{LR})}\right] \Big/ \sigma(\mathrm{LR})$.
  - $\Delta > 0.5$ for poorly-prepared/lower aptitude students (Kulik et al. 1990), compared to < 0.4 for well-prepared/high-aptitude ones.
  - One expects that students with good preparation/high aptitude to score well on tests no matter how they're taught.
  - But those students finish the course quickly, leaving the students with poorer preparation, to their benefit, to face the less-divided attention of the instructors.

Why mastery/self-paced physics? (continued)

- By the same token: well-prepared/high-aptitude students complete the course in a fraction of the term, leaving them extra time for their other courses.
  - In one MSP physics course, the A students typically completed the course in 70% of the term.
- In follow-up studies, the test-performance lead of MSP students continues to grow after the class is over: that is; the material sticks better if learned in MSP than in LRE.
  - In eight studies, Δ increased from 0.5 to 0.65 in 8-40 weeks.

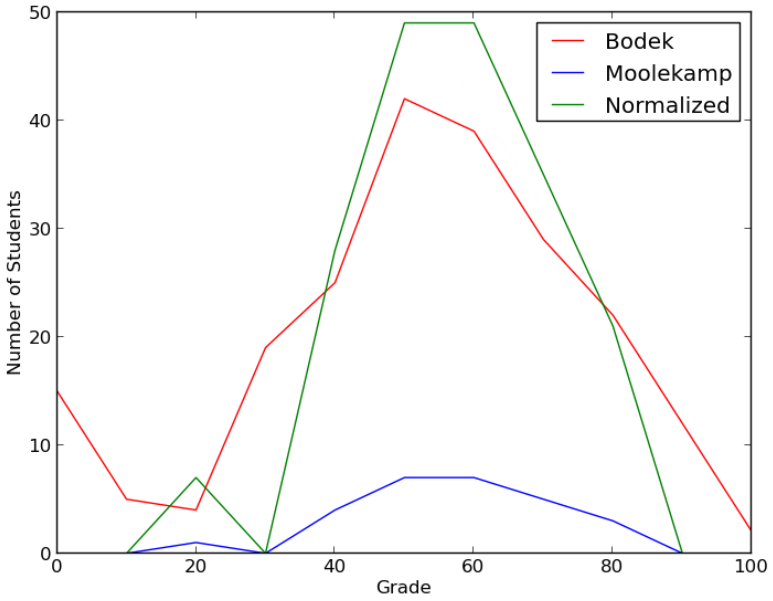
Thus the mastery/self-paced format is demonstrated to be better than the forced-pace, lecture-recitation style for all students, and confers the largest benefits on the wings of the preparation/aptitude distribution.

Why mastery/self-paced physics? (continued)

- These gains were also verified locally in a pilot study, Summer 2013, using PHY 113 and 114 as a testbed (50 students), and employing a final exam given in these classes a few years before to about 200 students.

  - Lower 60% of the MSP class ("Moolekamp") had almost the mean as the entire LRE comparison class ("Bodek").

  - The low-performing tail to low grades in LRE is not present in MSP.



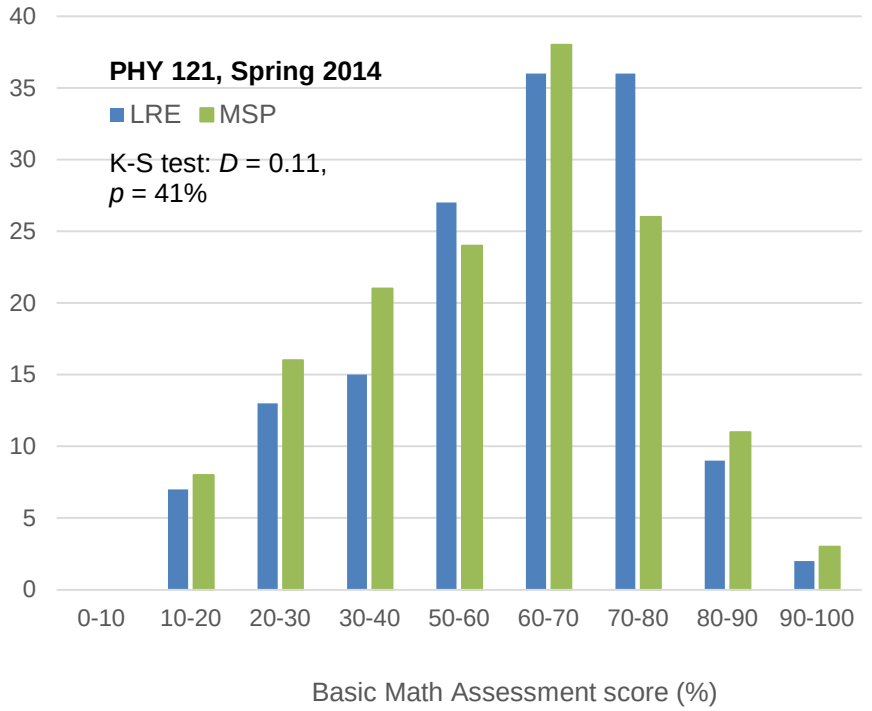
Final-exam histograms: Fall 2010 (red), lower 60% of Summer 2013 (blue), and lower 60% of Summer 2013 scaled to the same number of students as Fall 2010 (green).

Rollout of MSP physics, and a controlled experiment

UR's first regular semester, large-scale implementation was PHY 121/121P in Spring 2014. The College (i.e. Barbara Masi) and the department devoted considerable assessment resources for this event.

- Good fortune: a **controlled experiment** on outcomes was possible, as PHY 121 and 121P were equal in size and statistically indistinguishable in preparation.

- Conducted **mixed-mode assessments** and **common final-exam assessment**, in addition to Basic Math Assessment and information from math courses.



Insignificantly-different basic math preparation.

Controlled experiment (continued)

Results (Masi et al. 2015):

- MSP students scored significantly higher on the common final exam than LRE students.
  - By $\Delta = 0.4\sigma$ class-wide; K-S $D = 0.15$, $p = 7\%$.
  - By $\Delta = 1.2\sigma$ for students whose math performance placed them at risk for poor PHY 121/121P performance (STEM Gems).

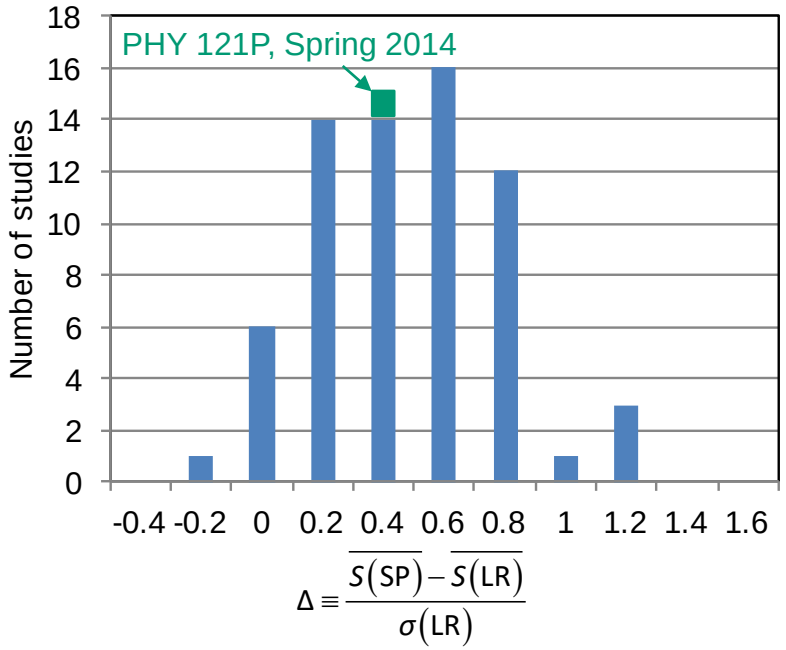
Group	MSP mean score	LRE mean score
All students (1)	67.4 (SD 15.7) N=151	60.6 (SD 17.5) N=160
"At-risk" students (2)	(SD 14.1) N=36	39.0 (SD 14.9) N=27

(1) $t(309)=2.179$, $p<0.001$

(2) $t(62)=4.728$, $p<0.001$

Controlled experiment (continued)

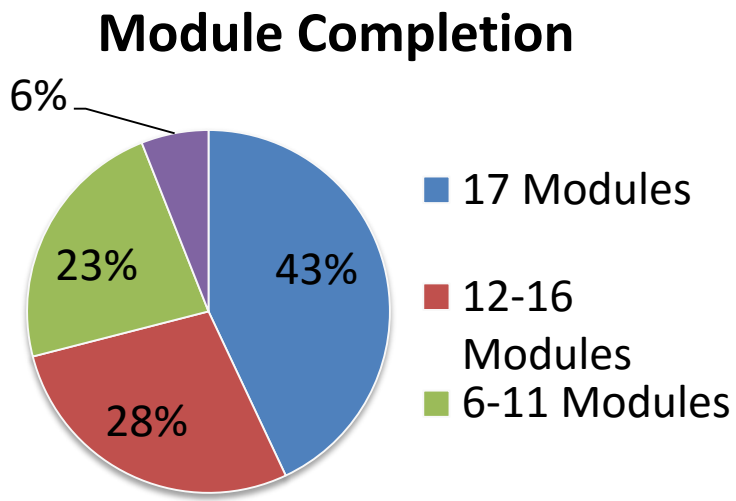
- Common-final-exam results consistent with the literature, by comparison with the metastudy by Kulik et al. 1990.
  - Also by comparison of "historical" experience of some of the instructors of this course, who had taken or taught MSP courses previously.

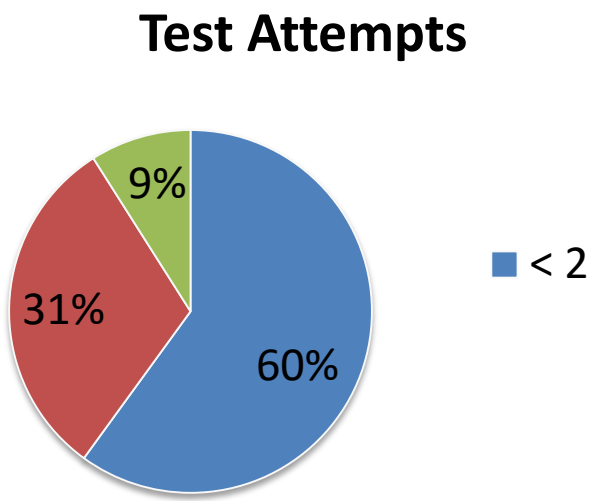


Data: Kulik et al. 1990

Tidbits from mixed-mode assessments

- No relationship was observed between student's pre-course characteristics and test-taking behavior.





Tidbits from mixed-mode assessments (continued)

- Student self-reporting indicated that confidence in the mastery of the material was significantly larger among the PHY 121P (MSP) students than among the PHY 121 (LRE) students.

Mastery of physics concepts	MSP N=52	LRE N=43
Not mastered	10%	16%
Moderately mastered	29%	48%
Strongly mastered	**61%**	**36%**

Why do many students come to like mastery/self-paced courses?

Besides the part about higher scores and better grades, it's

- **More personal attention from the instructors.** The workshop is open long hours and some combination of professor, graduate TAs and undergraduate TAs is always there.
- **More flexibility in learning.** Take extra time on a section one finds more troublesome; breeze through those that come more easily.
- **More control over one's grade**. 65-70% of the grade is simply the number of modules one has mastered; master them all and one has a perfect score for that portion of one's grade.
- **Mastery itself.** Students find that they have deeper understanding of the subjects they have studied in MSP classes than in traditional ones, even if they did well in both (see previous page).

Shortcomings of the mastery/self-paced format

Not many, but three deserve to be noted.

- **More expensive.** For the 8 studies that include instructional time per student in their observations, 6 find that SP students take more than LR students. The increase, averaged over the eight studies, is 4%.
  - Spring 2014: PHY 121P (MSP) cost almost $80k more than PHY 121 (LRE). Much of this was course-development investment.
- **Smaller course-completion rates**. Lower by 15% **in general**, but by a good deal less in math, physics and chemistry (average -1.7%).
  - **But not here**: in Spring 2014, the MSP course had a better completion rate (82%) than the LRE version (70%), and this has held subsequently.
- Needs **three dedicated rooms in close proximity**, for workshop (large), quiz room (large), and instructors/grading (small).

How a mastery/self-paced class works

In PSI (Keller-plan) classes like our PHY 121P and 122P,

- The course material is divided into modules – perhaps 16-17 per semester, for each of which the instructors provide a study guide, textbook-reading and video-viewing assignments, and homework problems to use to prepare for the module's **quiz**.

- Students can study in a **workshop**, in small groups or individually, with instructors facilitating and coaching.

  - The workshop – in a fixed location – is usually staffed long hours: in PHY 121P/122P it's open 2-10 PM, M-F.

- When a student feels prepared to demonstrate **mastery** in a module, s/he asks an instructor to take a quiz.

- After becoming convinced that the student *is* ready, the instructor issues a quiz (new to the student) randomly selected from a bank of 5-10 quizzes of closely similar difficulty, and sends them to the nearby **quiz room**.

How a mastery/self-paced class works (continued)

- The student takes the quiz immediately. These tests are designed to be finished in 15-30 minutes, and are closely proctored.

- Upon completion, the instructor grades the quiz immediately, in the presence of the student. Usually it takes a score of at least 90% to demonstrate mastery; in many classes the demand is 100%. The instructors retain the quiz, pass or fail.

- If the student does not pass, the instructor – using this as a prime teachable moment – discusses the concepts behind the quiz problems with the student, guides the student in avoidance of the mistakes s/he just made, and recommends practice problems…

  - …whereupon the student retreats to the workshop and uses the advice just received to prepare for another attempt: a different quiz on the same module.

  - There is **no penalty for failing a quiz**.

How a mastery/self-paced class works (continued)

- When a student passes a quiz, s/he moves on to the next module: studying, solving problems, and preparing again to demonstrate mastery in that material.

- Students repeat this process for each module, each **moving at her/his own pace**, until either they have finished each module or the end of the semester arrives. They all take a comprehensive final exam.

  - If the MSP class has run in parallel with an equivalent LRE class, the two classes usually take the same final exam. This will be the case for our PHY 120-level courses.

- A student's final grade is based upon how many modules s/he has mastered, her/his final exam score, and her/his lab score.

  - Normally, MSP and LRE sections share laboratory sections.

How a mastery/self-paced class works (continued)

Roles of instructors:

- In workshop, all instructors function as facilitators and coaches. **There are no regularly scheduled lectures.**
  - MSP students are welcome to attend the lectures in the LR section of the course. In practice, very few do.
  - In PHY 121P and 122P, the lectures in PHY 121 and 122 are recorded and posted on YouTube, for the class's asynchronous use. (They were recorded ahead of time in the pilot PHY 113 and PHY 114.)
- The **professor** is as usual responsible for creation/maintenance of study guides, reading and homework assignments, video lectures and demonstrations, quizzes, and exams, and of course supervises the TAs. Serves "at large" in workshop. Stoutly resists lecturing.

How a mastery/self-paced class works (continued)

- **Graduate TAs** each serve 16-20 hours weekly as facilitator/coach in workshop, and as issuers/graders of quizzes. They help all comers, but have primary responsibility for some 40-60 students who have registered for workshop at the times their TAs are scheduled.

- **Undergraduate TAs** play the same roles as graduate TAs, but only serve some 6 hours per week and have primary responsibility for 10-15 students.

  - Here they are chosen from among our department's trained pool of teaching interns (TIs), most of whom are physics, physics and astronomy, or engineering majors in their sophomore or senior years.

  - Peer learning is an important dynamic in a workshop: undergraduate TAs are particularly effective and valuable in self-paced classes.

- Grading statistics for all TAs are monitored regularly; large differences in quiz pass rates need to be detected, and understood or modified.

Mastery/self-paced FAQs, from students, faculty and administration

- *Are PHY 121P/122P online courses? I didn't come here to take online courses!*

  No it's not, and we wouldn't ask a UR student to take one. In many ways, MSP classes are the opposite of online classes, as they offer practically as many hours per week of face-to-face, individual attention as one could conceivably use. PHY 121P and 122P have websites (under BlackBoard) on which are found many course resources, but these are not MOOCs.

- *You mean to tell me that you would allow students to pass such classes without passing all of the modules?*

  Yes we do. And, as we've seen, they do better on the final than the students who you think have learned *all* the material in the LRE course, because in MSP, students *master* what they pass.

Mastery/self-paced FAQs (continued)

- *Self-paced instruction sounds a lot like "flipped classroom" teaching. Is it?*

  Just the workshops and the lack of regularly-scheduled lectures. Few "flipped classrooms" use mastery or self-paced methods.

- *If I lack the self motivation wouldn't this class be harder?*

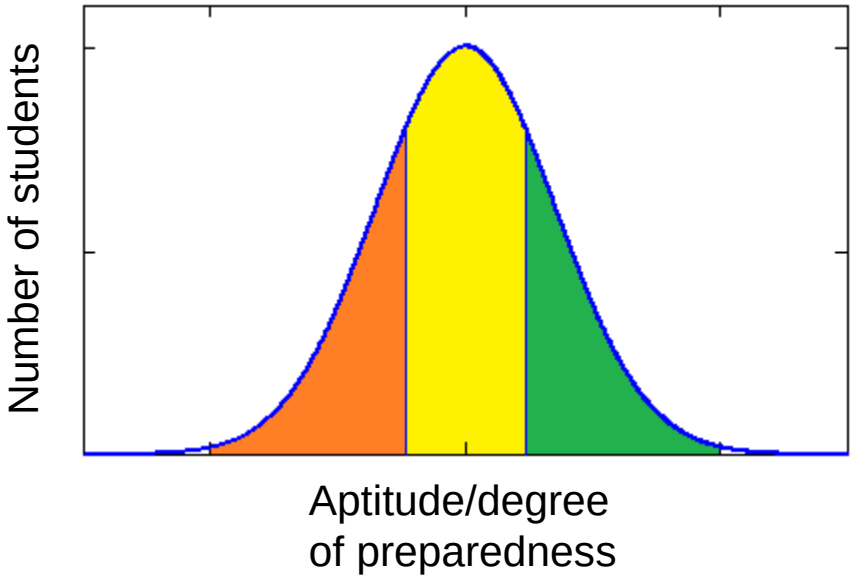
  Self-motivation is crucial to success in all classes, not just self-paced ones. If you mean "won't this class be harder on me since I won't be forced by the lectures to stay on pace?", we would say No. If you attend the Workshop frequently the instructors will bug you to keep up.

- *What if a student exhausts the bank of quizzes for a module?*

  This is very rare, due to the personal guidance provided when a quiz is flunked. But the professors simply make up additional quizzes.

Helping students choose between LRE and MSP

Caveat: no matter which they choose, students will still need to have done everything possible to build up their pre-physics skills before taking PHY 121/121P. The correct choice will ensure that most small gaps in a student's background, and some large ones, will be closed during these courses, but it won't save a student with a poor grasp of basic math and calculus.

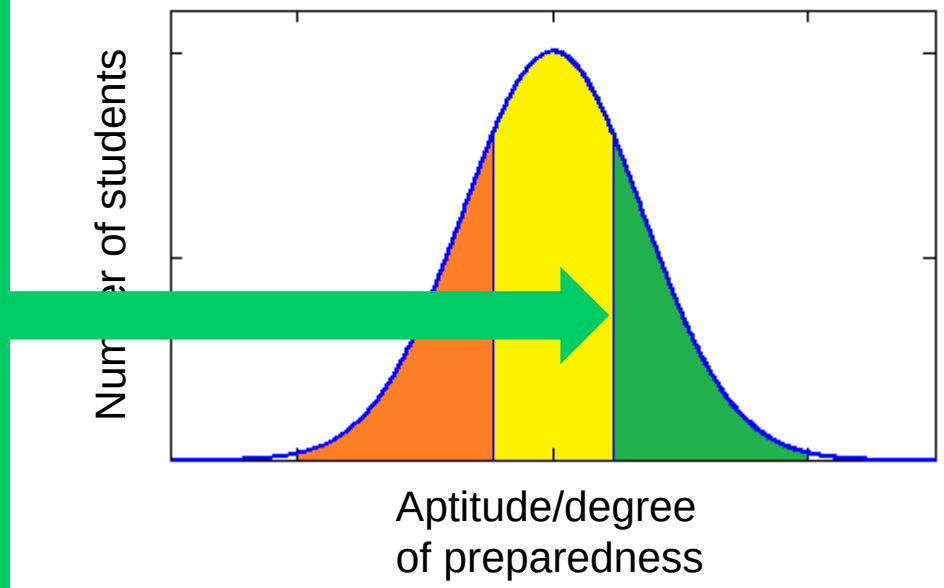


Helping students choose between LRE and MSP (continued)

- Advise well-prepared and/or very bright students to take the MSP versions, PHY 121P/122P.

  Advantages:

  - Will finish all the modules weeks before the end of the semester, leaving more time and effort available for other courses.

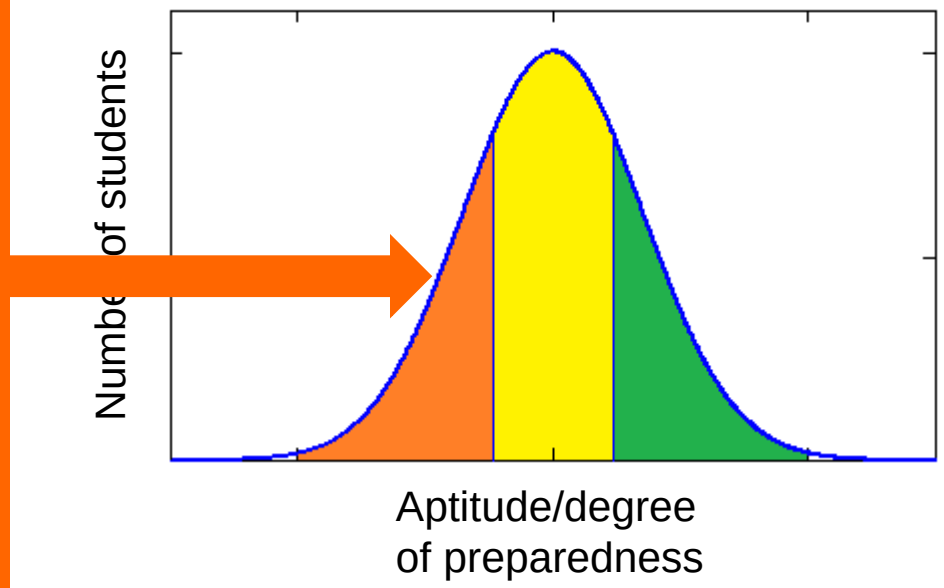


Helping students choose between LRE and MSP (continued)

- Advise students who aren't so well prepared to take PHY 121P/122P.

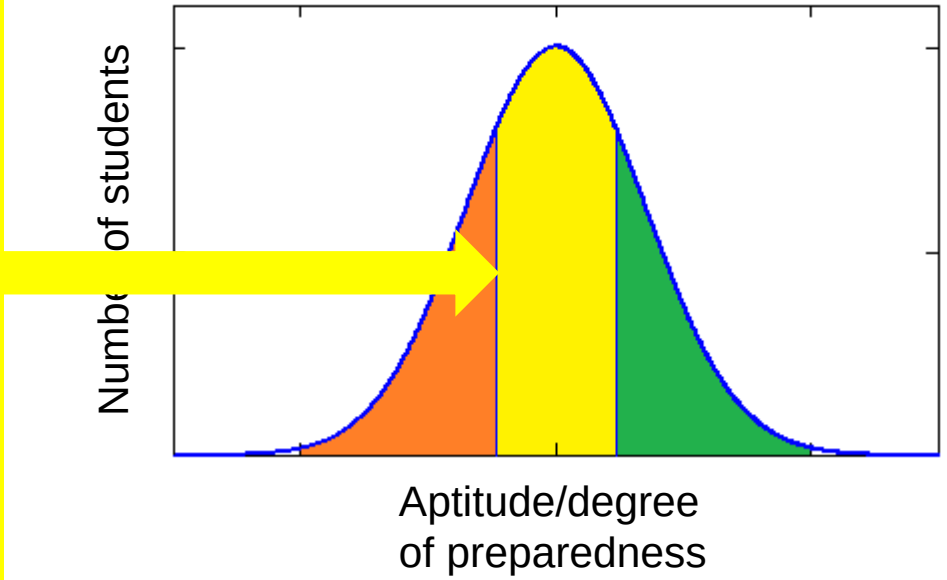
  Advantages:

  - Gaps in preparation will be identified by instructors far earlier.
  - More personal, individual attention to address those gaps; less demanding of additional tutoring resources.



Helping students choose between LRE and MSP (continued)

- For the rest of the students the choice should be more a matter of personal taste regarding live lectures.
  - The pace in the LR section is designed for the students near the peak of the distribution.
  - But even for such students, MSP has been **demonstrated** to be a more effective way to master the concepts, as we saw above.



Mastery/self-paced instruction: selected references

1. F.S. Keller 1968, *Good-bye, teacher…*, J Appl Behav Anal 1, 79.

   Locus classicus for the Personalized System of Instruction (PSI; Keller Plan) and self-paced instruction.

2. S.M. Austin & K.E. Gilbert 1973, *Student performance in a Keller-plan course in introductory electricity and magnetism*, Am J Phys 41, 12.

   A course just like our PHY 122P.

3. D.G. Born & M.L. Davis 1974, *Amount and distribution of study in a personalized instruction course and in a lecture course*, J Appl Behav Anal 7, 365.

4. C.C. Kulik, J.A. Kulik & R.L. Bangert-Drowns 1990, *Effectiveness of mastery learning programs: a meta-analysis*, Rev Educ Res 60, 265.

   Includes 72 controlled studies of PSI and lecture-recitation classes, which demonstrate that students perform better in PSI by about 0.5σ.

Current instances of mastery and/or self-paced instruction: selected resources

1. Eric Mazur (Dept. of Physics, Harvard): mazur.harvard.edu/education/educationmenu.php.

   1990s popularizer of computer-aided peer instruction in Keller-plan-like and forced-pace implementations, and the idea of professors serving in workshops ("guide on the side") instead of lecturing ("sage on the stage").

2. Computer-aided personalized system of instruction (CAPSI): www.capsi.org.

   Direct descendant of the Keller Plan. Oriented toward the social sciences but has a few tools we would find useful.

3. B. Masi, D.M. Watson, A. Bodek, D.A. Khaitan & E. Garcell, *Comparison of mastery learning and traditional lecture-exam models in a large enrollment physics course,* https://peer.asee.org/23719. The result of our controlled experiment with PHY 121/121P.
   Nominated for Diversity Paper of the Year by ASEE; received honorable mention.