ACTIVE LEARNING IN UNDERGRADUATE MATHEMATICS COURSES: WHAT WE KNOW, WHAT WE'RE PRETTY SURE OF, AND WHAT WE STILL NEED TO FIGURE OUT

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WHY ARE WE TALKING ABOUT ACTIVE LEARNING

- "Less than 40% of US students who enter university with an interest in STEM, and just 20% of STEM-interested underrepresented minority students, finish with a STEM degree" (Freeman et al. 2014)
- "Data show that approximately 40 percent of undergraduate students leave engineering programs, 50 percent leave the physical and biological sciences, and 60 percent leave mathematics." (Seymour & Hewitt, 1997)
- "Of all students who enter college intending to major in a STEM field, recent studies estimate that only 40–50% (varying by discipline) complete a degree in a STEM major" (Seymour & Hunter, 2019)

WHY ARE WE TALKING ABOUT ACTIVE LEARNING

Course DWF Rates	All Dept	PhD	MA
Pre-calc	27.36% (of 232)	27.09% (of 134)	27.73% (of 98)
Calc 1	22.07% (of 288)	20.66% (of 191)	24.85% (of 97)
Calc 2	20.05% (of 264)	18.20% (of 180)	23.95% (of 84)

Progress through Calculus (PtC, NSF DUE #1430540)
2015 - Survey of all mathematics departments offering a graduate degree in mathematics
67.6% (223/330): 75% (134/178) of PhD-granting departments and 59% (89/152) of the MA/MS-granting departments

WHY ARE WE TALKING ABOUT ACTIVE LEARNING

"In these courses, there is content overload, incoherent presentation, curve grading, with material pitched too high and inappropriately abstract, a focus on rote learning, boring delivery—in other words, mind-numbing, something to be endured rather than enjoyed—the exact opposite of what you get with inclusive pedagogy and active learning." (Seymour & Hunter, 2019)

- Problems with poor teaching in STEM courses
- Problems with STEM curricular design include content overload, pace of delivery, and poor alignment between course elements

COMMON VISION

"The status quo is unacceptable"

"We see a general *call to move away from the use of traditional lecture* as the sole instructional delivery method in undergraduate mathematics courses … Even within the traditional lecture setting, *we should seek to more actively engage students than we have in the past.*" (p. 19)

- *Common Vision:* AMATYC, AMS, ASA, MAA, SIAM

WHAT WE KNOW ABOUT ACTIVE LEARNING

Active learning increases student performance in science, engineering, and mathematics (Freeman et al., 2014)

- Meta-analysis of 225 studies that reported data on exam scores or failure rates when comparing student performance in undergraduate STEM courses under traditional lecturing versus active learning
- "Results indicate that average examination scores improved by about 6% in active learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning."
- "The results raise questions about the continued use of traditional lecturing as a control in research studies, and support active learning as the preferred, empirically validated teaching practice in regular classrooms."

IN THE AGGREGATE

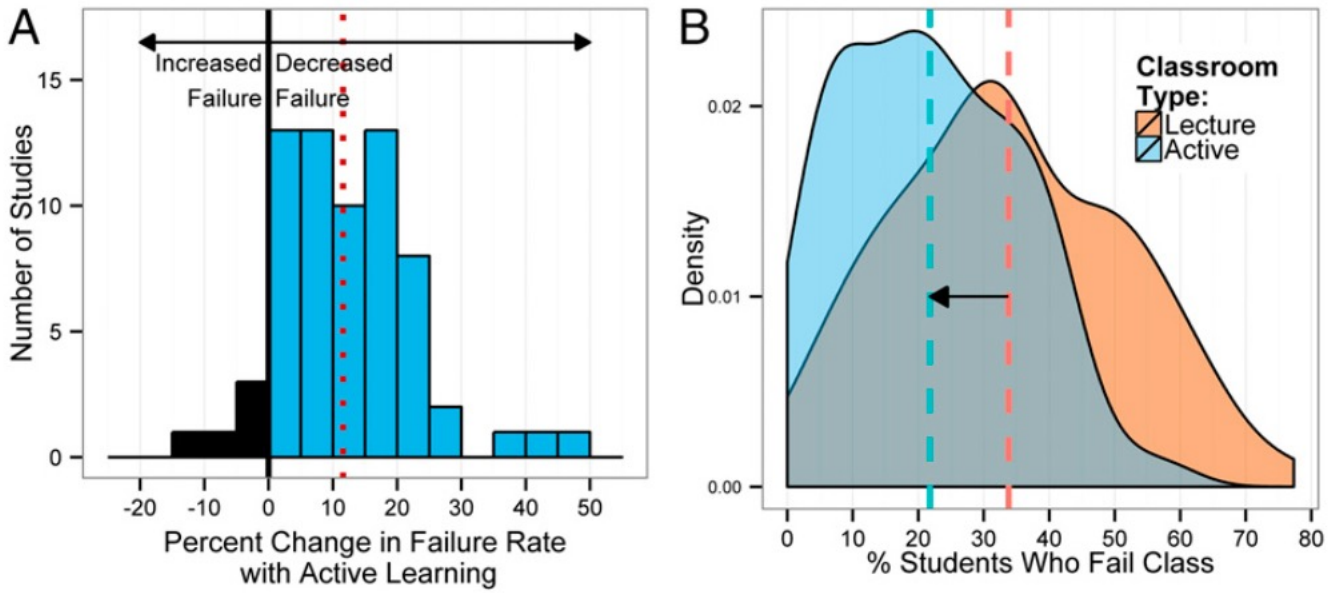

Fig. 1. Changes in failure rate. (*A*) Data plotted as percent change in failure rate in the same course, under active learning versus lecturing. The mean change (12%) is indicated by the dashed vertical line. (*B*) Kernel density plots of failure rates under active learning and under lecturing. The mean failure rates under each classroom type (21.8% and 33.8%) are shown by dashed vertical lines.

(Freeman et al., 2014, p.8411)

MATHEMATICS STUDIES INCLUDED IN THE META-ANALYSIS

Alsardary S, Blumberg P (2009) Interactive, learner-centered methods of teaching mathematics. PRIMUS. 19(4):401–416.

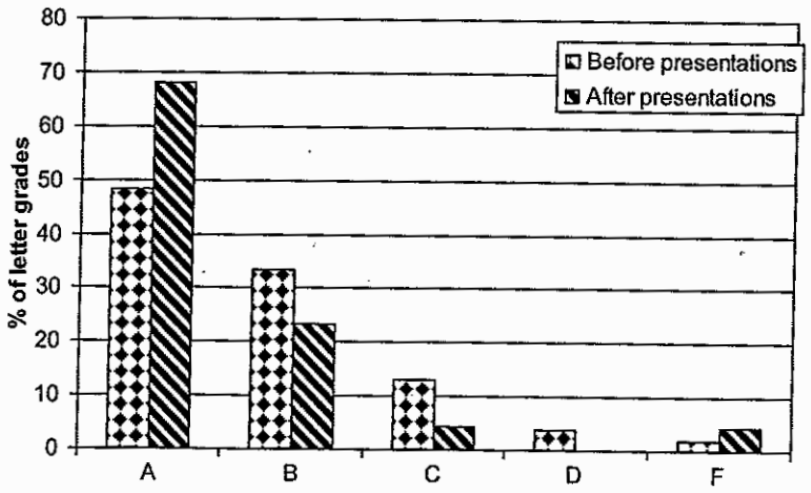

Figure 2. Comparison of grades prior to 2003 before the interactive, learner-centered methods were introduced in the Discrete Mathematics course. We compared the grades in the course for the 15 times the instructor taught the course before in a less interactive way with the 7 times he has taught it using these methods. We used a Large sample Z test for two independent proportions. The proportion of As in the course is significantly increased after using this type of approach, whereas the change in the other grades is not significant.

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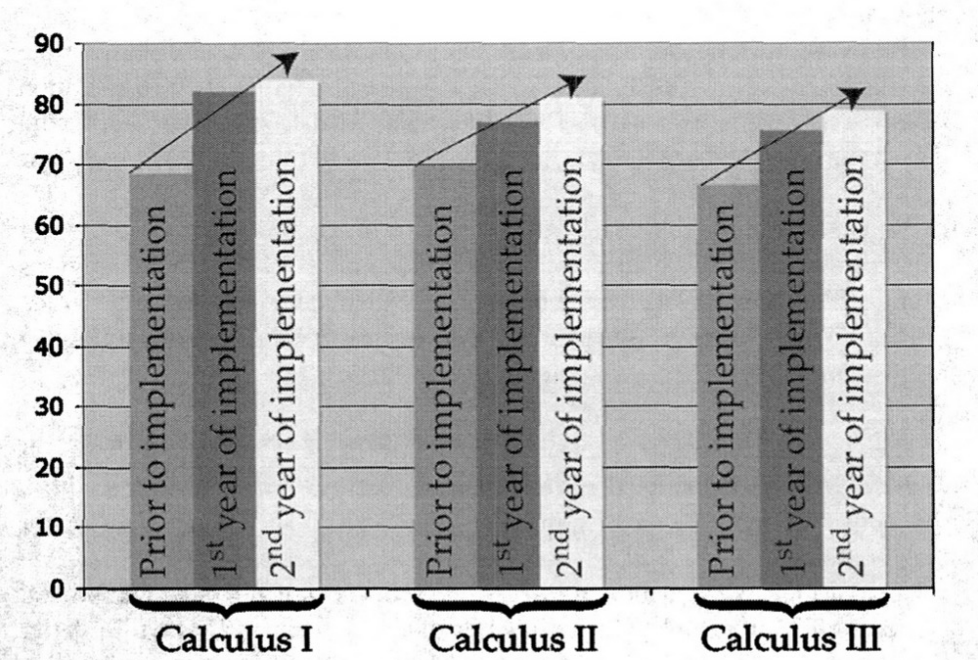


Figure 1. Percentage of students earning letter grades of A, B, or C.

Ellington AJ (2005) A modeling-based college algebra course and its effect on student achievement. PRIMUS. 15(3):193–214.

Modeling Approach			Traditional Approach	
ABC	71.83		ABC	49.70
DFW	28.17		DFW	51.30

Table 3. Percentage of Students Passing Each Course for Fall 2004.

RESULTS IN PUBLISHED RESEARCH ARTICLES

Preponderance of evidence points to active learning being beneficial to student outcomes.

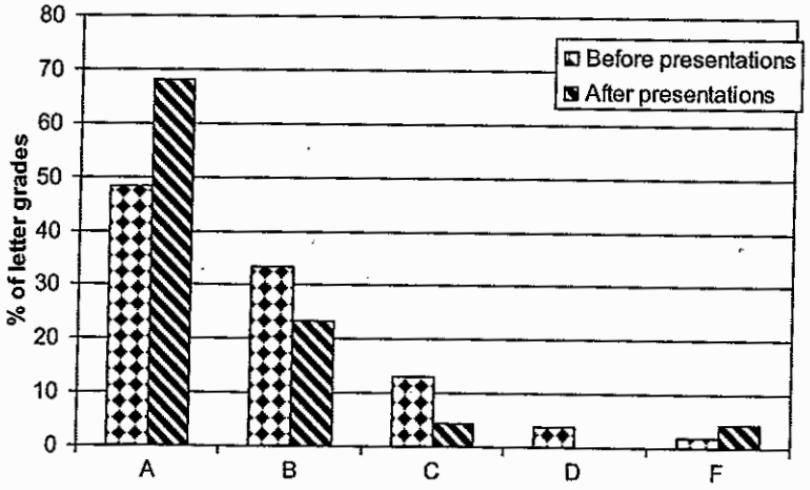
BUT WHAT IS ACTIVE LEARNING?

"The active learning interventions varied widely in intensity and implementation, and included approaches as diverse as occasional group problem-solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course designs." (Freeman et al., 2014)

“ACTIVE LEARNING” IN THE MATH INTERVENTIONS

Alsardary S, Blumberg P (2009) Interactive, learner-centered methods of teaching mathematics. PRIMUS. 19(4):401–416.

"This course uses different learner-centered activities that are consistent with the goals for the course, including a student-faculty interactive presentation of content presentation in the class, homework, student presentations on an applied topic of their choice, and interactive, take-home examinations." (p. 404)



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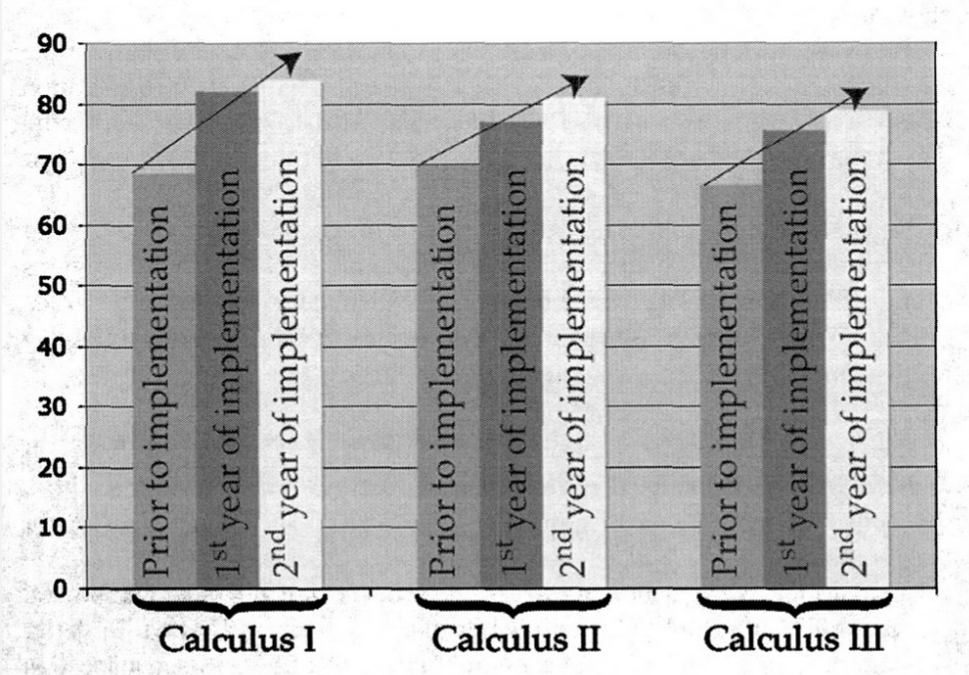
"students participate in a 1-hour collaborative learning session (a workshop) twice a week. During a typical workshop, they work collaboratively in small groups on worksheets that are provided by the instructor." (p. 287)



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“50 minutes consisted of students working on modeling problems in groups of 2-4 with intermittent pauses for whole- or partial-class discussion on issues that would arise or skills that needed to be reinforced while students were working.” (p. 198)

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DFW	28.17		DFW	51.30

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EXAMPLES FROM THE TITLES OF THE OTHER STEM STUDIES

- "Discovery-Based Instruction"
- "Cooperative Learning"
- "Studio Format"
- "Cloning the Professor"
- "Hybrid Lecture–Online"
- "Audience Response Systems"
- "Challenge Based Instructional Modules"
- "Small Group Learning"
- "Student Active Learning Pedagogies"
- 'Constructivist Based Strategies"
- "Increased Course Structure"
- "Hot Seat Questioning"
- "Cooperative Learning"
- "Discussion in Small Groups"
- "Problem Based Learning"
- "Learning by Writing"
- "Interactive Engagement"
- "Online Homework System"
- "Writing Summaries"
- "Peer Instruction"
- "Tablet PC-enhanced interactivity"
- "Multimedia"
- "Clickers"
- "Personalized System of Instruction"
- "Unannounced Quizzes"
- "Weekly Quizzes"
- "Computer Based"
- "Active-engagement microcomputer-based laboratories"
- "Guided Inquiry"
- "Networked Tools"
- "Daily Class Progress Assessment"
- "Peer Assessment"
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INTERPRETATION

Doing literally anything is better than lecture, continuing to lecture is actually harmful

"The results raise questions about the continued use of traditional lecturing as a control in research studies, and support active learning as the preferred, empirically validated teaching practice in regular classrooms." (Freeman et al., 2014)

CONTINUED USE OF "TRADITIONAL LECTURING"

"The active learning interventions varied widely in intensity and implementation, and included approaches as diverse as **occasional group problem-solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course designs**." (Freeman et al., 2014)

How many people are doing nothing but talking? Not even worksheets or clickers or "occasional" group work?

RBIS SURVEY (2019)
1349 CALC I OR II INSTRUCTORS, 635 INSTITUTIONS

RBIS	Current users	RBIS	Current users
Small-Group Work		PLTL	
Comp Sim, Anim		Concept Inventories	
Think-Pair-Share		Just-in-Time Teaching	
IBL		POGIL	
Peer Instruction		Reform-Oriented Textbooks	
Flipped Classroom		Concept Maps	

RBIS SURVEY (2019)
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RBIS	Current users	RBIS	Current users
Small-Group Work	51%	PLTL	18%
Comp Sim, Anim	45%	Concept Inventories	17%
Think-Pair-Share	37%	Just-in-Time Teaching	17%
IBL	29%	POGIL	13%
Peer Instruction	24%	Reform-Oriented Textbooks	12%
Flipped Classroom	18%	Concept Maps	10%

RBIS SURVEY (2019)
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RBIS	rrent ers
Small-G	%
Comp	%
Think-l	%
IBL	%
Peer In	%
Flippec	%

73% report currently doing at least one of these "active learning" techniques.

OF THOSE 1349…

- 82 instructors (6% of respondents) report lecturing for more than 90% of the class time

- 52% of respondents report lecturing for more than 50% of class time

Evaluating the Uptake of Research-Based Instructional Strategies in Undergraduate Chemistry, Mathematics, and Physics
National Science Foundation under Grant Nos. IUSE DUE-1726328, 1726281, 1726042, 1726126, and 1726379.

INTERPRETATION

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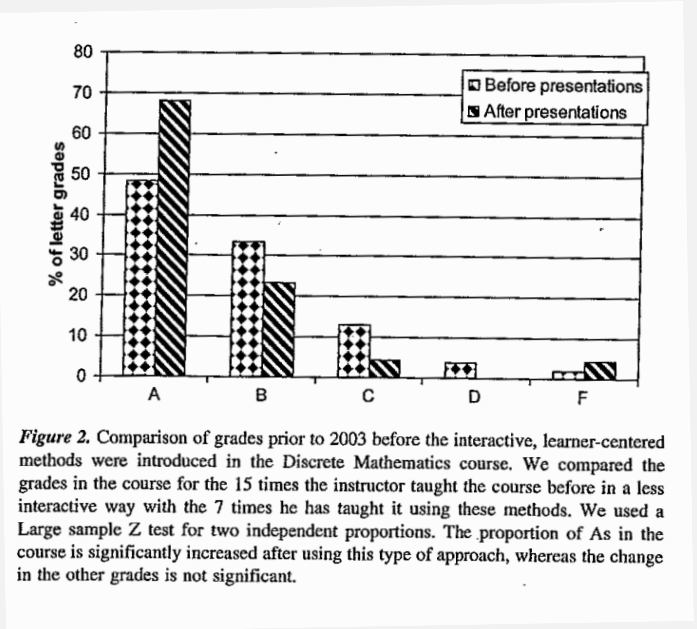
I don't think that captures the *research*

INTERPRETATION #2

Thoughtful educators who are systematically trying to improve their teaching (by increasing student engagement during class time) are generally successful.

Alsardary S, Blumberg P (2009) Interactive, learner-centered methods of teaching mathematics. PRIMUS. 19(4):401–416.

- Teacher had taught this class 15 times. They then completely reorganized the course to: have students be the ones that make the formal presentations of the content; requiring students to present their mathematical work at MAA section meetings, changes exams to be take-home with an in person interview component.
- Teacher then teaches the class this way another 7 times, collects and compares grade distribution data, authors/collaborated on a research article.



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Complete overhaul of the calculus sequence.

- Diagnostic testing
- Development of a "calculus infused with pre-calc" year-long sequence for students who are not ready for the traditional "engineering calc" sequence.
- Collaborative Learning: In addition to the 4 hours of lecture introduced an additional 1-hour workshop that meets twice a week
- Required "large scale" applied project for students
- Increased coordination on exams
- Proactive early warning system

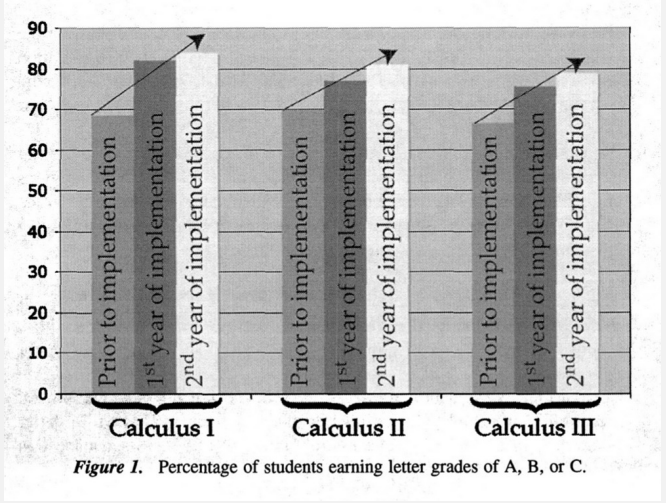

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Table 3. Percentage of Students Passing Each Course for Fall 2004.

"The mathematics department decided to pilot a major change to college algebra"

- Instructors met weekly to co-plan
- 50 minutes of collaborative work on modeling problems
- Group projects to explore real world applications
- Restructuring of content and assessments
- Evaluation of results

GOAL

Thoughtful educators who are systematically trying to improve their teaching (by increasing student engagement during class time)

- Instructor attitudes and beliefs
- Local supports
- Departmental Environments

INSTRUCTOR ATTITUDES AND BELIEFS

INSTRUCTOR ATTITUDES AND BELIEFS

Survey Item	Very strong	Moderately strong	Mildly strong	Not at all
Participating in activities that raise your awareness of how students learn key ideas in calculus?	36.9%	39.0%	20.0%	4.1%
Improving your own teaching?	64.8%	27.4%	6.7%	1.1%

(Data for this table can be requested at: **https://www.maa.org/programs/faculty-and-departments/curriculum-development-resources/national-studies-college-calculus/data-for-researchers.***)*

Fall 2010: 700 Calculus I instructors at 212 colleges and universities, both 2- and 4-year programs
Characteristics of Successful Programs in College Calculus (CSPCC, NSF DRL #0910240)

	Disagree				Agree			
Survey Item	**All**	**Bach**	**Mast.**	**PhD**	**All**	**Bach**	**Mast**	**PhD**
I think lecture is the best way to teach. (n = 217)	41%	49%	41%	32%	59%	52%	59%	68%
I think lecture is the only way to teach that allows me to cover the necessary content. (n = 214)	47%	55%	51%	35%	53%	45%	49%	65%
I think students learn better when they do mathematical work (in addition to taking notes and attending to the lecture) in class. (n = 216)	13%	7%	11%	23%	87%	93%	89%	77%
I think students learn better when they struggle with the ideas prior to me explaining the material to them. (n = 215)	23%	25%	27%	17%	77%	75%	73%	83%
I think students learn better if I first explain the material to them and then they work to make sense of the ideas for themselves. (n = 217)	40%	40%	32%	60%	61%	60%	68%	41%

(Johnson, E., Keller, R., & Fukawa-Connelly, T. (2018). Results from a survey of abstract algebra instructors across the United States: Understanding the choice to (not) lecture. International Journal of Research in Undergraduate Mathematics Education, 4(2), 254-285. Reprinted with permission from Springer Nature.)

219 abstract algebra instructors from PhD, Master's, and Bach granting mathematics departments, 2015/2016

	Disagree				Agree			
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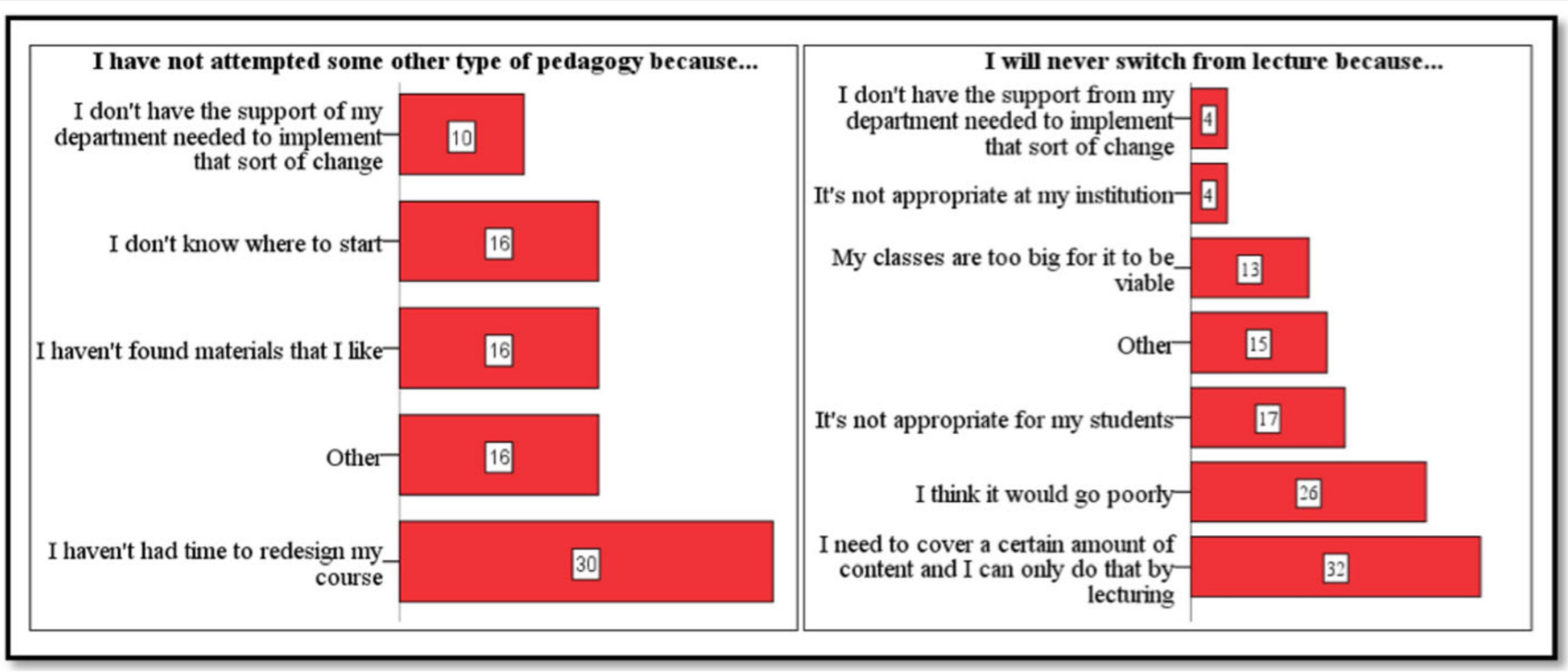
LOCAL SUPPORTS/CHALLENGES



129 AA instructors from PhD and Master's granting mathematics departments, 2015

Table 5 Departmental support items cross-tabulated by instructional style

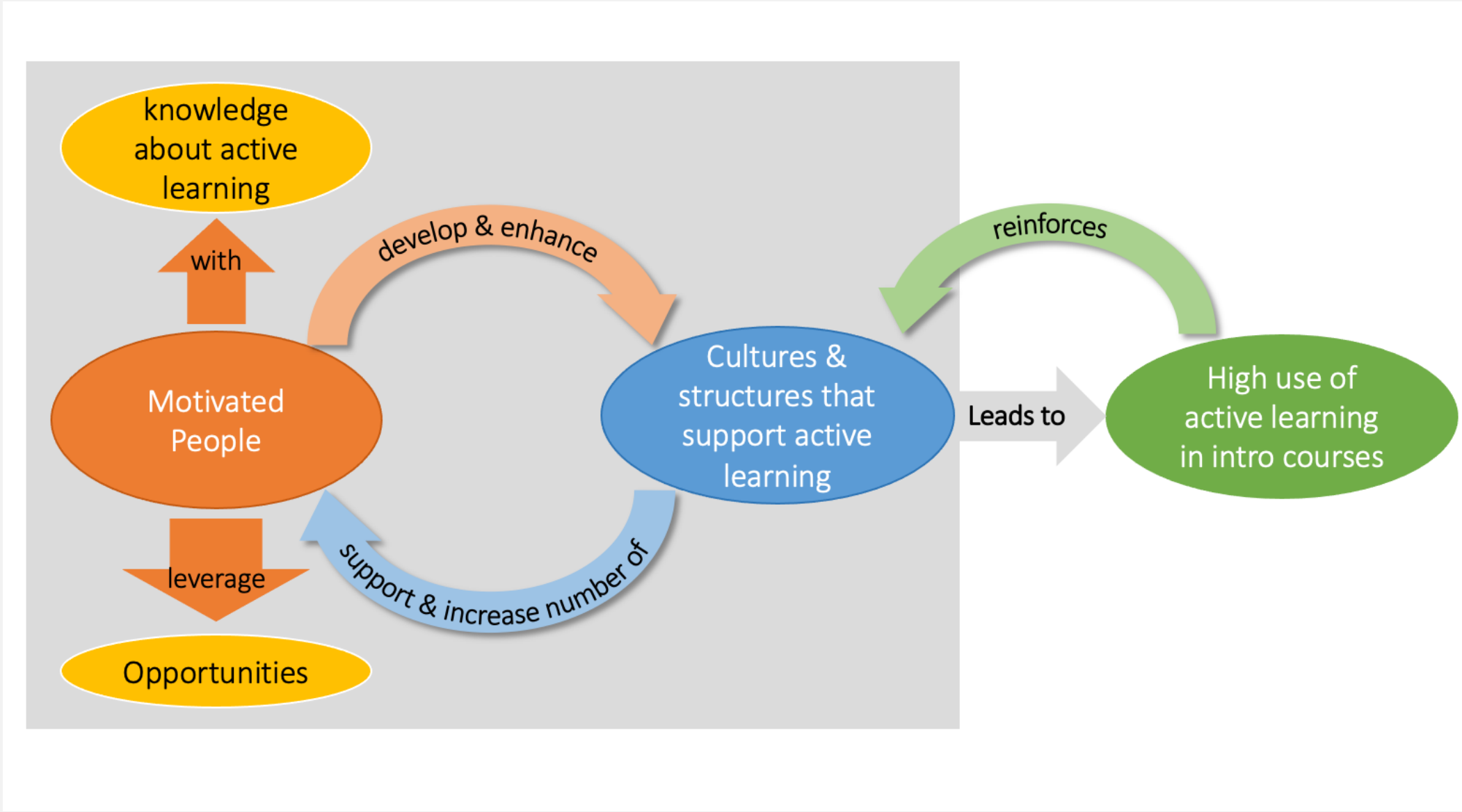
Do you feel pressure from your department to cover a fixed set of material?	Yes	Maybe	No
Limited lecturers	28.95%	N/A	71.05%
Moderate lecturers	29.75%	N/A	70.25%
Extensive lecturers	30.19%	N/A	69.81%
I believe I would have the freedom to make changes to the content of my course (e.g., including or excluding certain topics and/or textbook changes).	Yes	Maybe	No
Limited lecturers	78.59%	18.54%	2.63%
Moderate lecturers	75.61%	21.95%	2.44%
Extensive lecturers	74.55%	23.64%	1.81%
I believe I would have time to plan and redesign my course in a way that would be supported and valued in my annual review or P&T process.	Yes	Maybe	No
Limited lecturers	36.85%	44.74%	18.42%
Moderate lecturers	36.59%	39.84%	23.58%
Extensive lecturers	38.18%	41.83%	20.00%
I believe I would have travel support to attend professional development opportunities (e.g., Project NExT, MAA/AIM workshops).	Yes	Maybe	No
Limited lecturers	43.37%	44.74%	7.89%
Moderate lecturers	39.02%	41.46%	19.51%
Extensive lecturers	38.18%	47.27%	14.55%

N/A this was not a response choice for this item

219 abstract algebra instructors from PhD, Master's, and Bach granting mathematics departments, 2015/2016

SUPPORTIVE DEPARTMENTAL ENVIRONMENTS

Evaluating the Uptake of Research-Based Instructional Strategies in Undergraduate Chemistry, Mathematics, and Physics
National Science Foundation under Grant Nos. IUSE DUE-1726328, 1726281, 1726042, 1726126, and 1726379.



(A. Lau, C. Henderson, C. Merino, M. Stains, M. Dancy, E. Johnson, N. Apkarian, J. Raker, "Active learning in intro courses: A study of 18 high active learning use departments", AAPT Summer Meeting, 2021).

MOTIVATED PEOPLE

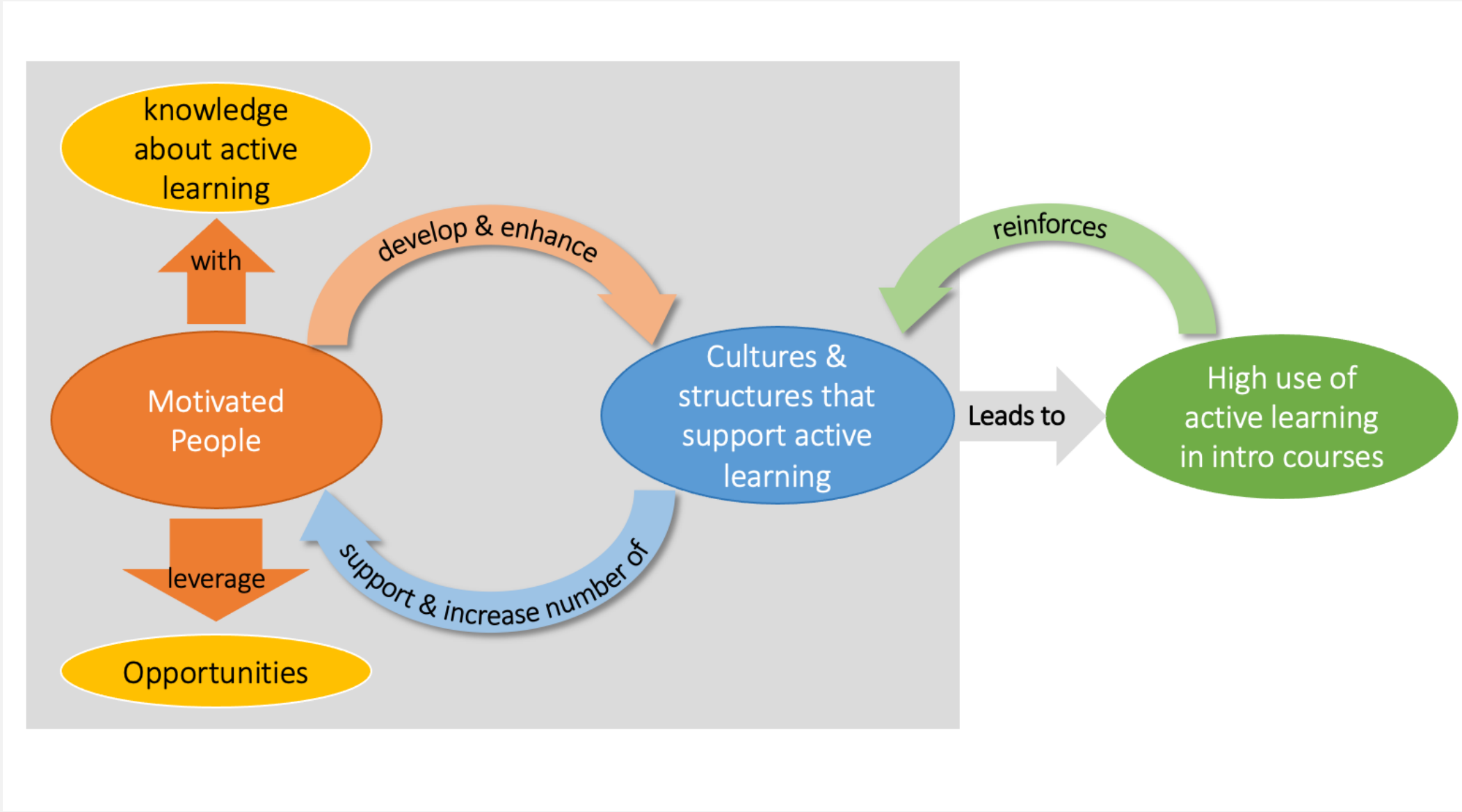
- Education Researchers
- Faculty (who are not education researchers)
- Department Chairs
- Institutional Leaders (e.g., Deans)

KNOWLEDGEABLE ABOUT ACTIVE LEARNING

- COMMIT Network
- MAA MathFest
- University of Michigan Center for IBL
- MAA Open Math Series
- Project NExT

LEVERAGE OPPORTUNITIES

- Funding opportunities (e.g., building active learning classrooms, developing curricular materials)
- Institutional Pressures (e.g. graduation rates/DFW),
- Strategic hiring



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CULTURES AND STRUCTURES THAT SUPPORT ACTIVE LEARNING

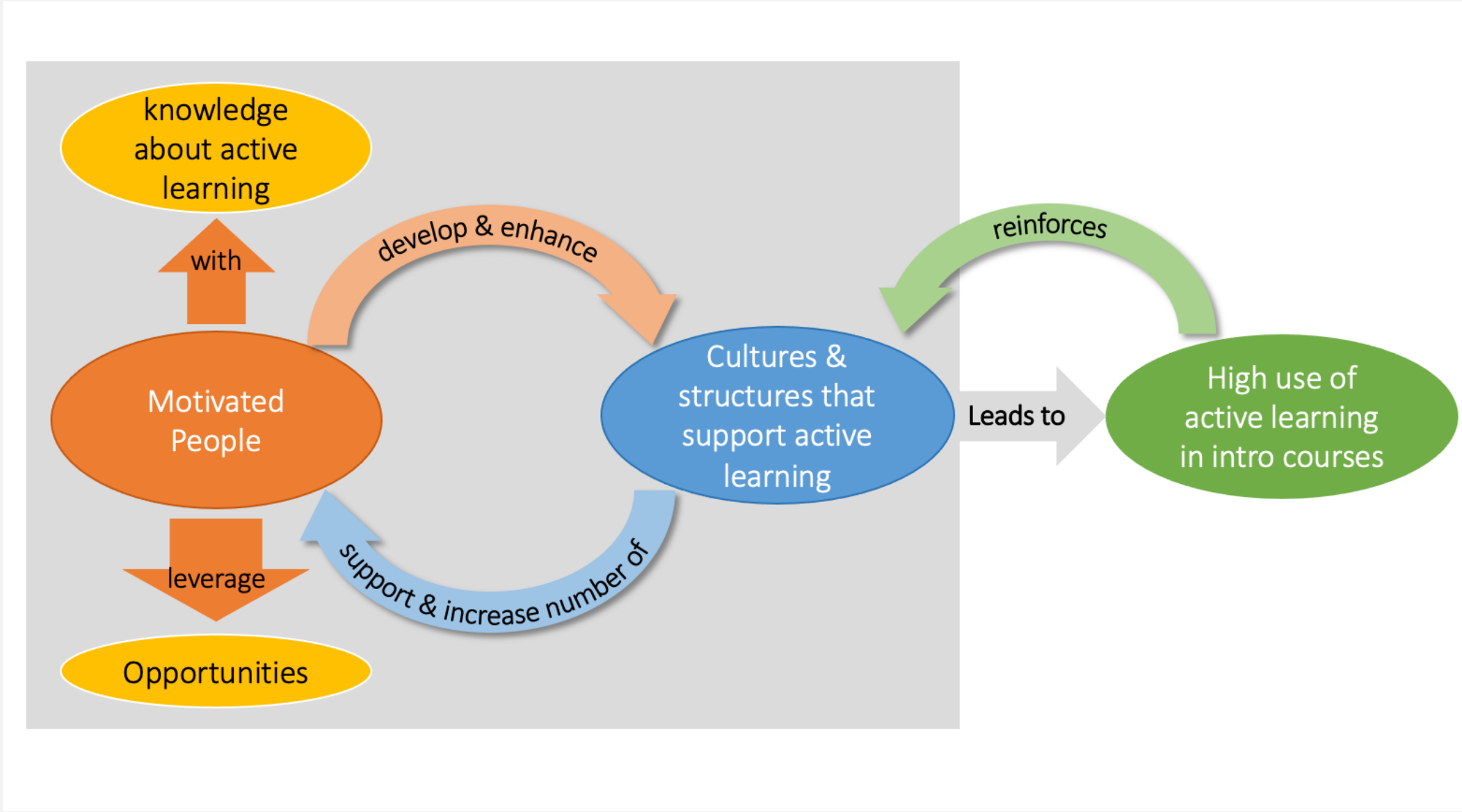
Institution-Level

- Value undergrad teaching
- Evaluation of teaching practices
- Teaching & Learning Center
- presence of educational researchers (DBER) on campus

CULTURES AND STRUCTURES THAT SUPPORT ACTIVE LEARNING

Department-Level

- Hiring for commitment to teaching innovation
- Culture of continual innovation and exploration (often supported by new faculty)
- Collaborative culture around teaching in department
- All faculty teach intro courses
- Send people to external professional development
- Class layout and/or size
- Common curriculum
- Active learning classroom
- Value undergrad teaching



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ADDITIONAL CONSIDERATIONS

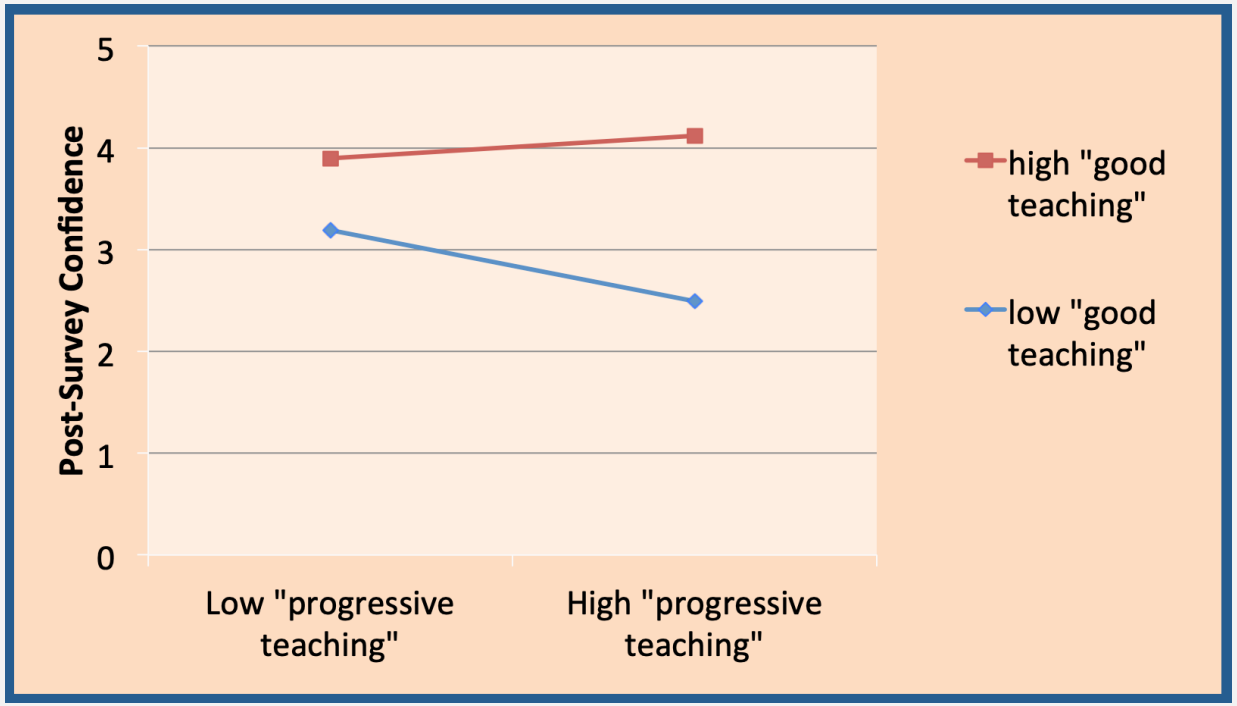
- Many priorities that can be considered
  - Active student engagement
  - Content requirements
  - Feasibility and instructor capacity
  - Inclusive environments and equitable outcomes

- Careful not to assume that one strategy is going to work for all of these considerations

BAD ACTIVE LEARNING IS STILL BAD!

BAD ACTIVE LEARNING IS STILL BAD!

Survey of 14,000+ Calculus I Students (2010) – End of Semester Report of Confidence Levels



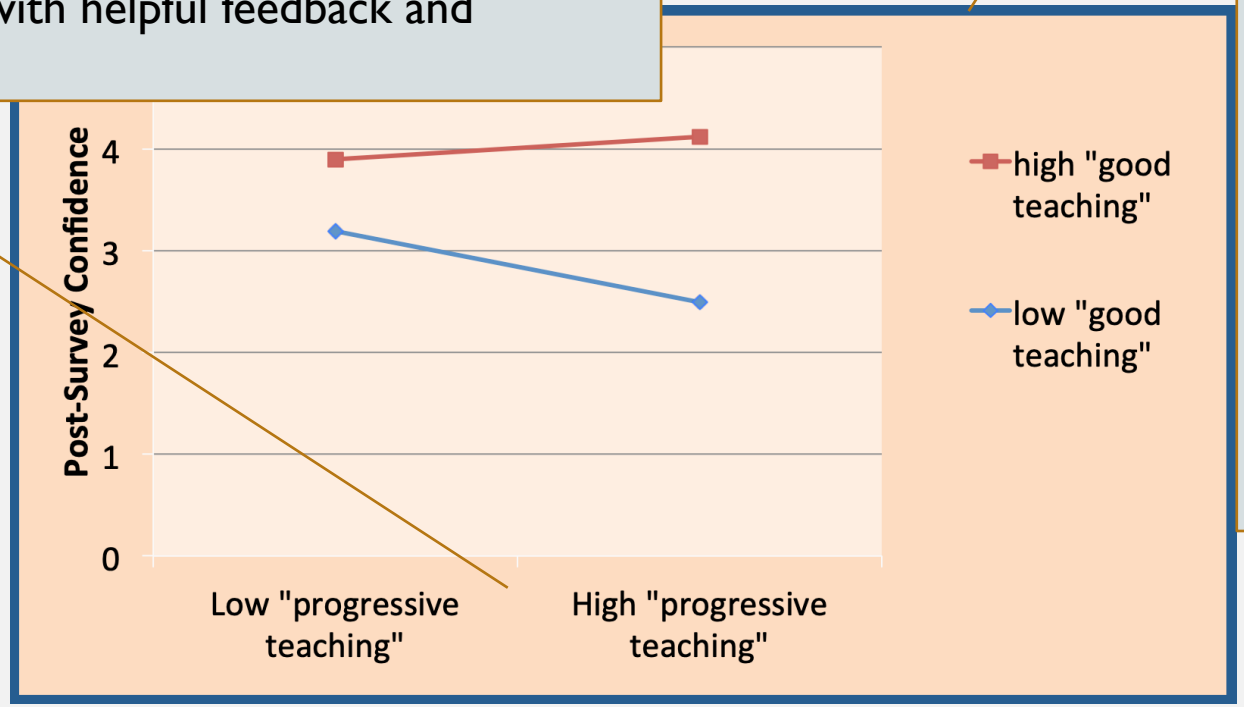
Bressoud, D. (2012) *Report on the MAA Calculus Study*. Presented to the AMS Committee on Education.

"Progressive Teaching" Factor

My Calculus Instructor:
- Required me to explain my thinking on homework and exams
- Required students to work together
- Had students give presentations
- Held class discussions
- Put word problems in the homework and on the exams
- Put questions on the exams unlike those done in class
- Returned assignments with helpful feedback and comments

RNING IS STILL

dents (2010) – End



"Good Teaching" Factor

My Calculus Instructor:
- Listened carefully to my questions and comments
- Allowed time for me to understand difficult ideas
- Presented more than one method for solving problems
- Asked questions to determine if I understood what was being discussed
- Discussed applications of calculus
- Encouraged students to seek help during office hours
- Frequently prepared extra material

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BAD ACTIVE LEARNING IS STILL BAD!

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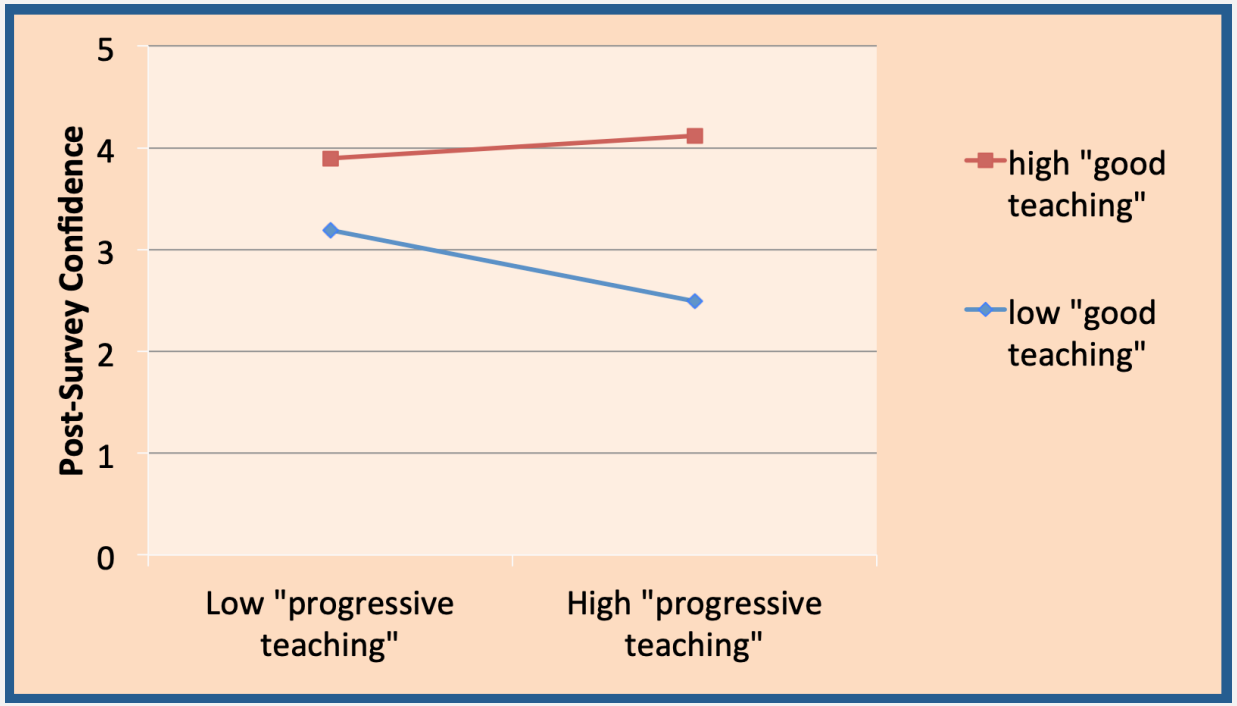

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DIFFERENTIAL OUTCOMES

TIMES

Teaching Inquiry-oriented Mathematics: Establishing Supports

Develop a model for supporting instructional change in undergraduate mathematics

1) Curricula materials
2) Summer workshops
3) Online working groups

TIMES EVALUATION

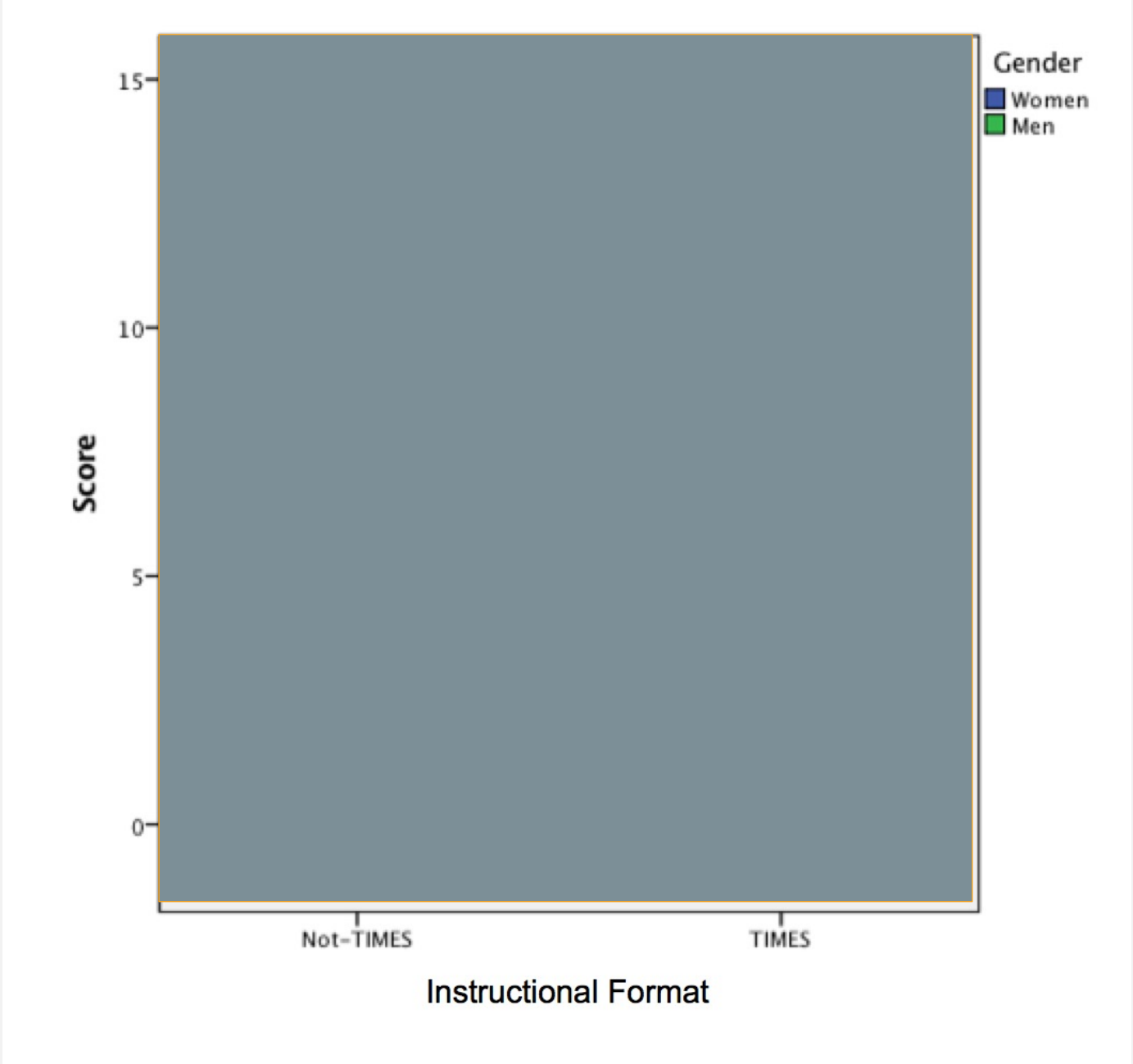
Analysis of IOAA - Group Theory Content Assessment (Melhuish, 2015).

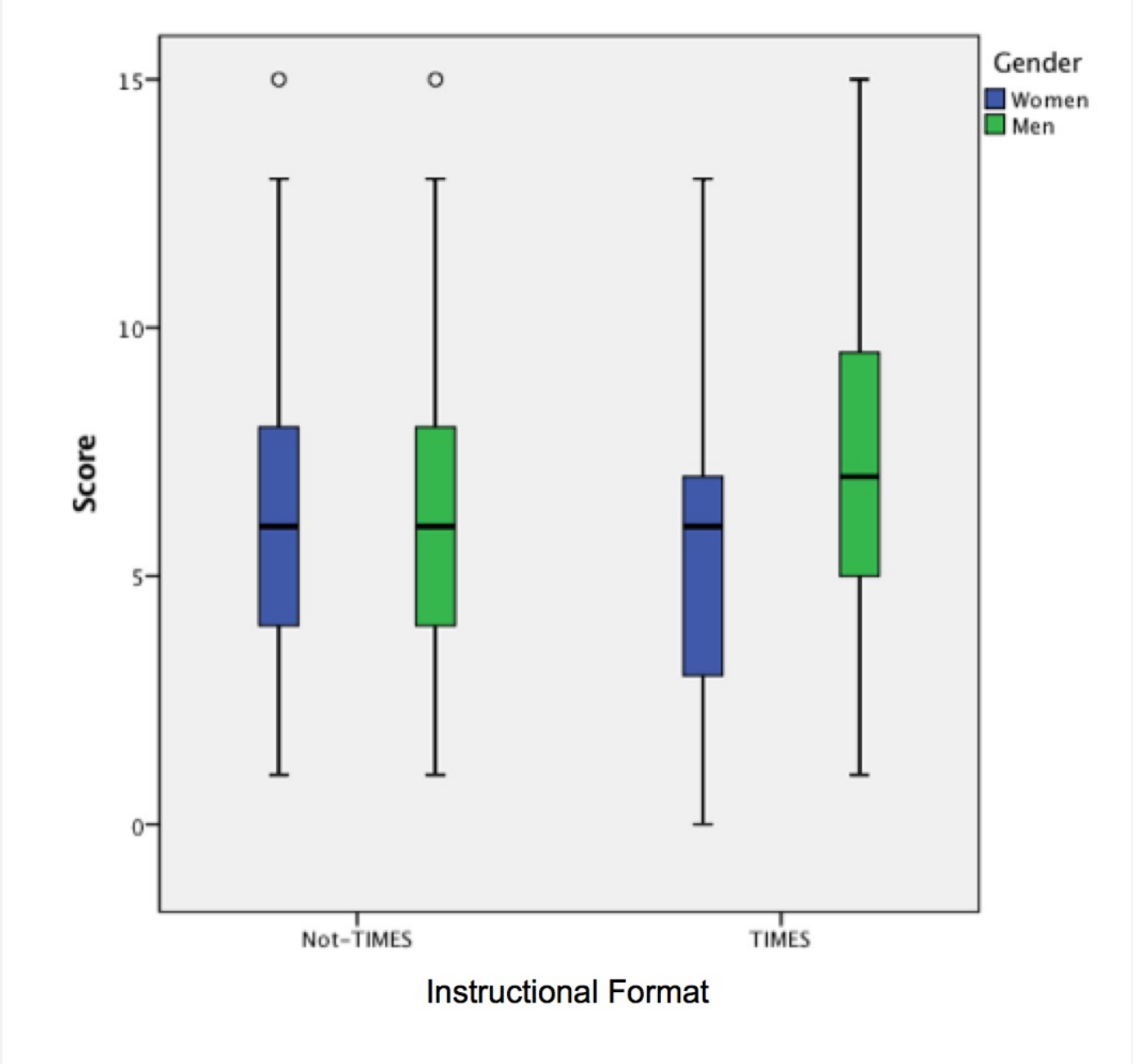
- From the 13 IOAA TIMES Fellows, there were a total of 174 students, 147 of whom (84%) completed the GTCA
- Control group (Not-TIMES), data from 375 students from 33 institutions

TIMES students slightly outperform the Not-TIMES

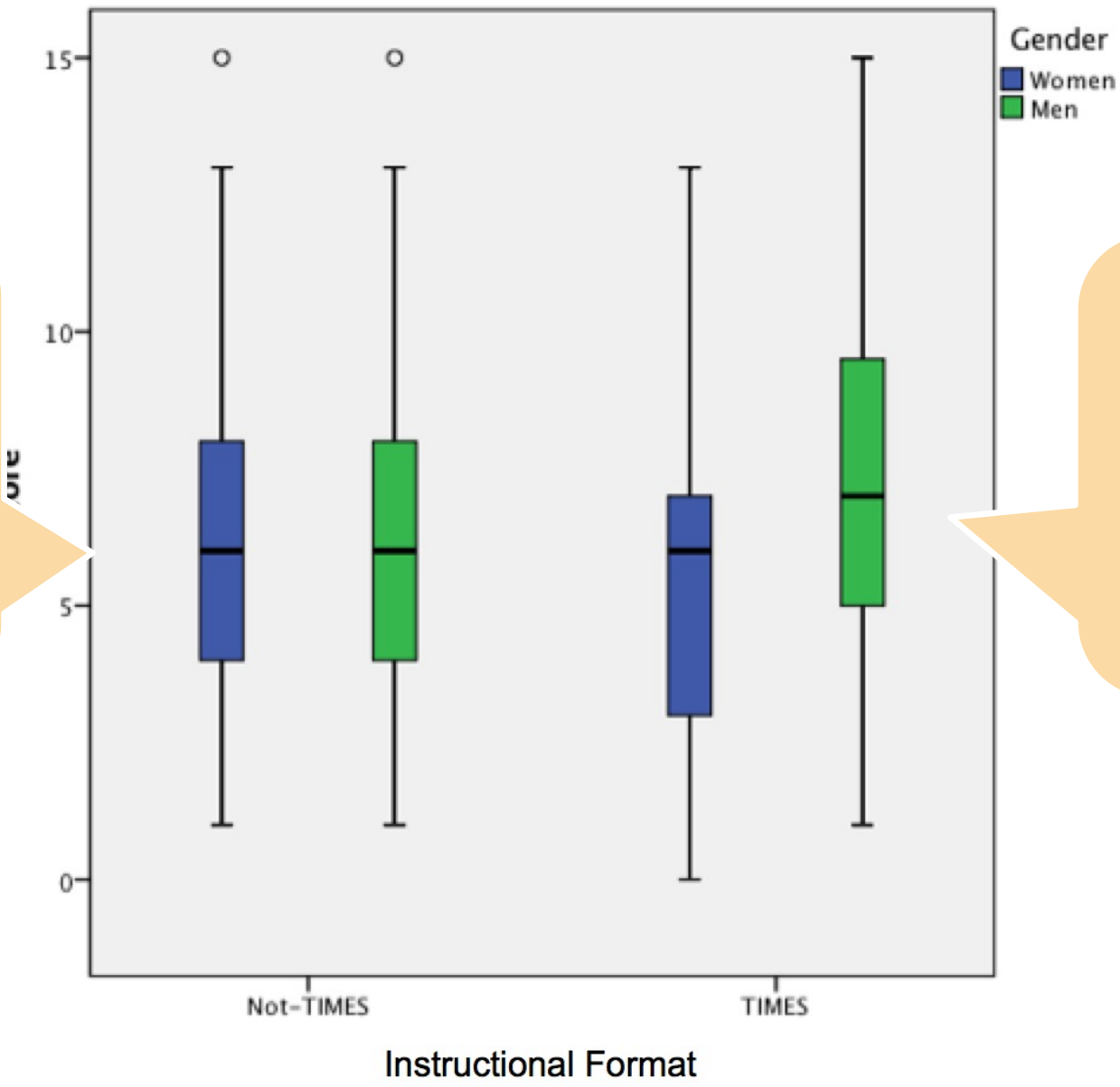
- about half an item (6.64 vs. 6.21)
- this difference is not statistically significant ($p = .129$)

Most "traditional" measure – we aren't hurting students!


Gender
Women
Men
15
10
5
0
Score
Not-TIMES
TIMES
Instructional Format

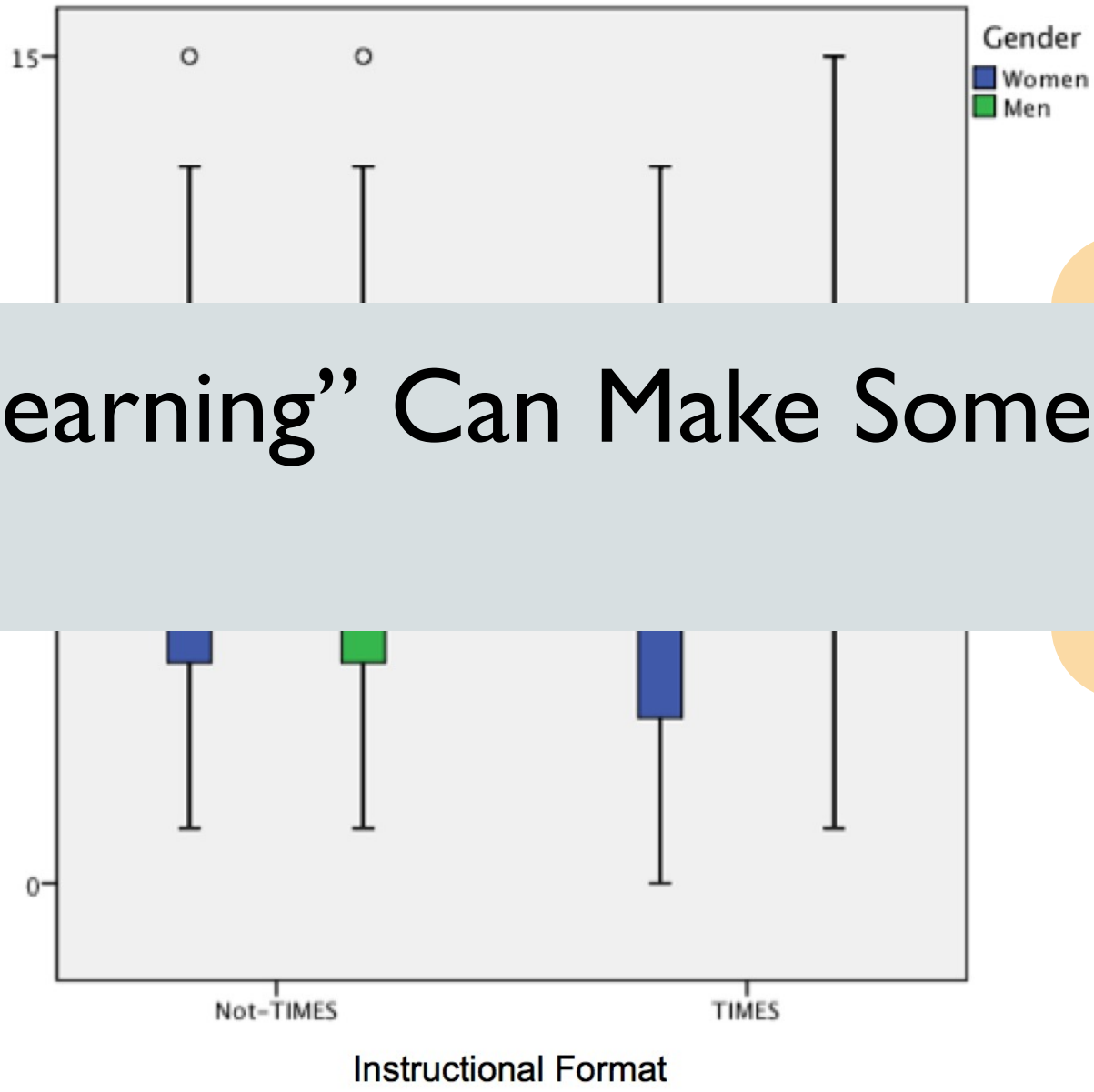

Gender
Women
Men
Score
15
10
5
0
Not-TIMES
TIMES
Instructional Format

No significant difference in the Not-TIMES group Men +.5 items on average ($p = .095$)



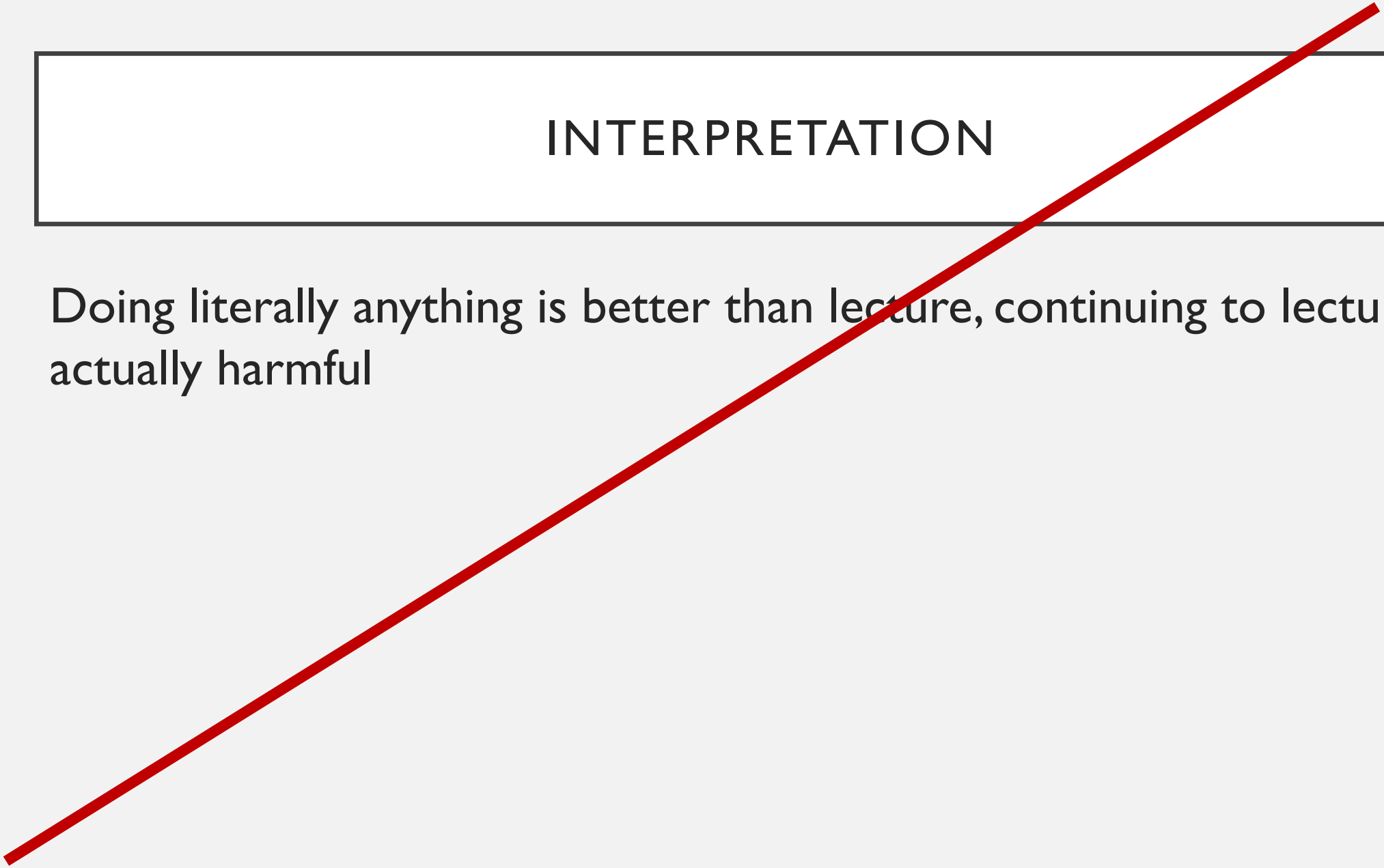
Significant difference in the TIMES group Men +2 items on average ($p < .001$) effect size ($d = .7257$)

“Active Learning” Can Make Some Things Worse!



INTERPRETATION

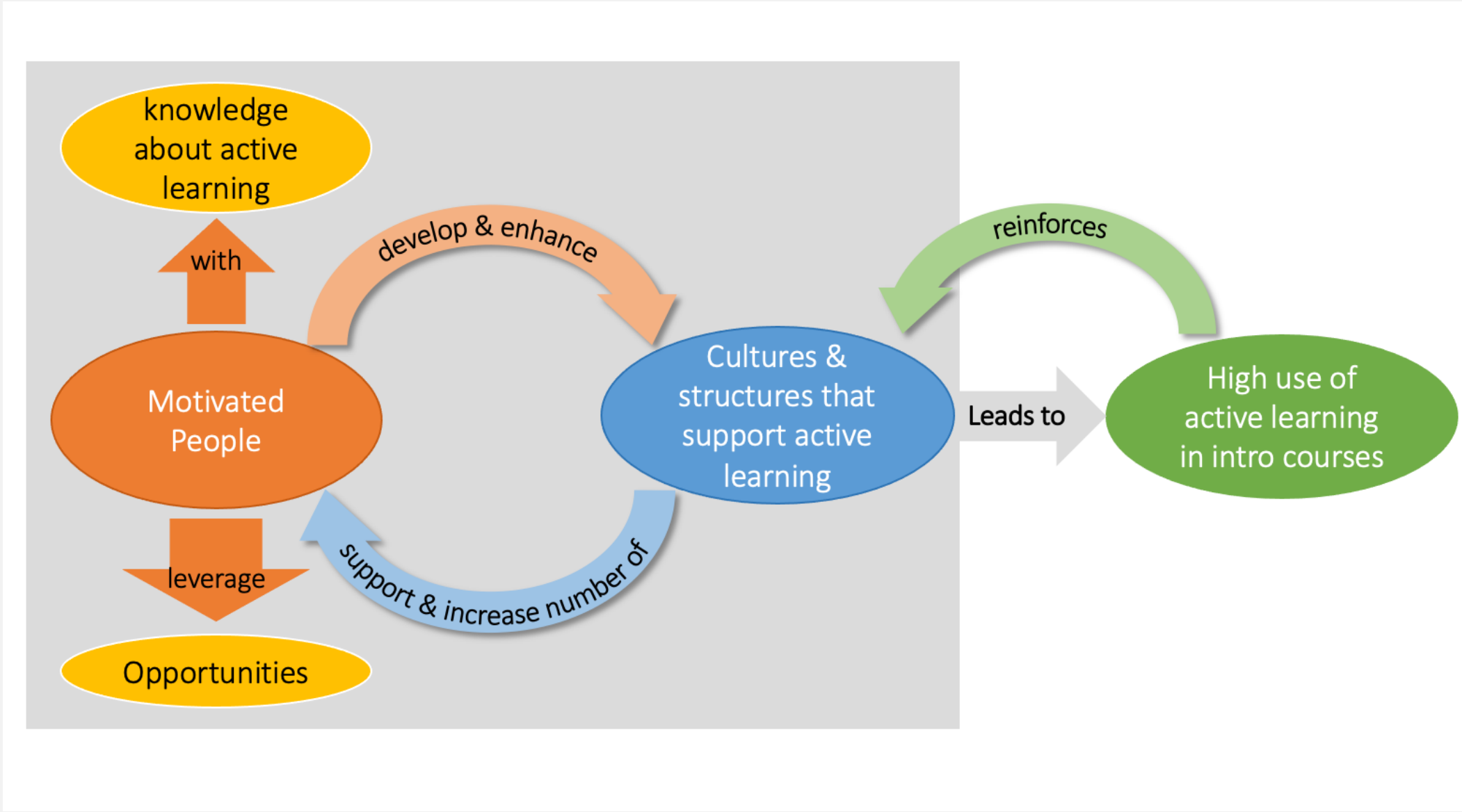
Doing literally anything is better than lecture, continuing to lecture is actually harmful



INTERPRETATION #2

Thoughtful educators who are systematically trying to improve their teaching (by increasing student engagement during class time) are generally successful.

And 64.8% of teachers have a VERY strong interest in improving their teaching.



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THANK YOU!