Importance of characterizing STEM faculty members' instructional mindsets and practices in an era of instructional transformation

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CREATE for STEM

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Research-based instruction can address national priorities

- Persistence of students in STEM fields and the preparation of a science-literate society are national priorities.

Fact:
Less than half of students entering colleges intending to major in STEM fields graduate with a STEM degree.

- The learning environment provided in STEM courses is an important lever to achieve these goals.

Fact:
Students often leave STEM because of the uninspiring instructional practices experienced in introductory courses.

- Research has demonstrated that certain instructional approaches can enhance student learning, attitude and persistence in STEM.

Olson, S., & Riordan, D. G. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. *Executive Office of the President*.
Seymour, E., & Hewitt, N. M. (1997). Talking About Leaving: Why Undergraduates Leave the Sciences. Boulder, Colorado.

There have been numerous initiatives to reform teaching

- Initiatives to transform instruction in STEM undergraduate courses have been on-going for decades.

SCIENCE EDUCATION

Challenge faculty to transform STEM learning

Focus on core ideas, crosscutting concepts, and scientific practices

By **Melanie M. Cooper*, Marcos D. Caballero, Diane Ebert-May, Cori L. Fata-Hartley, Sarah E. Jardeleza, Joseph S. Krajcik, James T. Laverty, Rebecca L. Matz, Lynmarie A. Posey, Sonia M. Underwood**

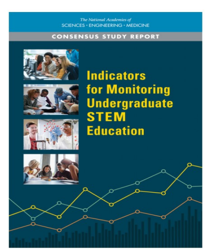
moting deep learning and is well aligned with other international initiatives. These strategies were developed for K-12 (primary and secondary education), but we believe the approach is valid for the first 2 years of college.

national-level initiatives and the research literature, we believe that core ideas must be negotiated locally by faculty in each discipline in order to build ownership and buy-in.
For example, core ideas that emerged from cross-disciplinary discussions at our

Cooper, M. M., Caballero, M. D., Ebert-May, D., Fata-Hartley, C. L., Jardeleza, S. E., Krajcik, J. S., ... & Underwood, S. M. (2015). Challenge faculty to transform STEM learning. *Science*, *350*(6258), 281-282.

Measuring the level of uptake is challenging

- "At present, however, policy makers and the public do not know whether these various initiatives are accomplishing their goals and leading to nationwide improvement in undergraduate STEM education." (p.1)



- A recent study provides some insight.

POLICY FORUM

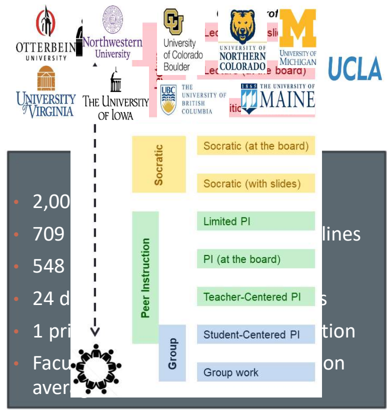
SCIENCE EDUCATION

Anatomy of STEM teaching in North American universities

National Academies of Sciences, Engineering, and Medicine. (2018). Indicators for monitoring undergraduate STEM education. National Academies Press.

Context of study

- Common instructional profiles can be identified among a population of STEM instructors.
- Expansion of the study helps explore generalizability of these profiles.



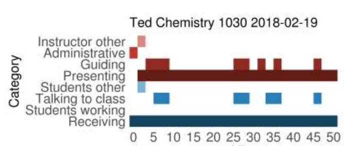
Lund, T. J., Pilarz, M., Velasco, J. B., Chakraverty, D., Rosploch, K., Undersander, M., & Stains, M. (2015). The best of both worlds: Building on the COPUS and RTOP observation protocols to easily and reliably measure various levels of reformed instructional practice. *CBE—Life Sciences Education*, *14*(2), ar18.
Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., ... & Levis-Fitzgerald, M. (2018). Anatomy of STEM teaching in North American universities. *Science*, *359*(6383), 1468-1470.

Methods

Instrument

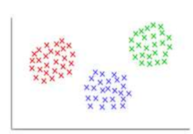
- COPUS: Classroom Observation Protocol for Undergraduate STEM

Smith, M. K., Jones, F. H., Gilbert, S. L., & Wieman, C. E. (2013). The classroom observation protocol for undergraduate STEM (COPUS): a new instrument to characterize university STEM classroom practices. CBE-Life Sciences Education, 12(4), 618-627.



Data Analysis

- Latent profile analysis using 8 codes:
  - Instructor: lecture, posing questions, clicker questions, and one-on-one work with students
  - Students: group work on clicker questions, group work on worksheets, other group work, and asking questions



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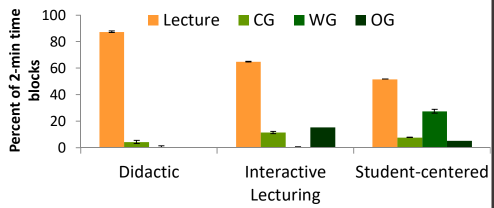
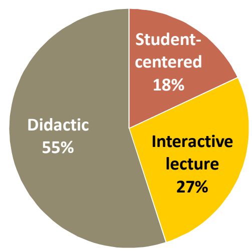
Three broad instructional styles were observed

- Seven clusters were identified which can be categorized in three broad categories:
  - Didactic
  - Interactive lecture
  - Student-centered



- Didactic was the most observed style.



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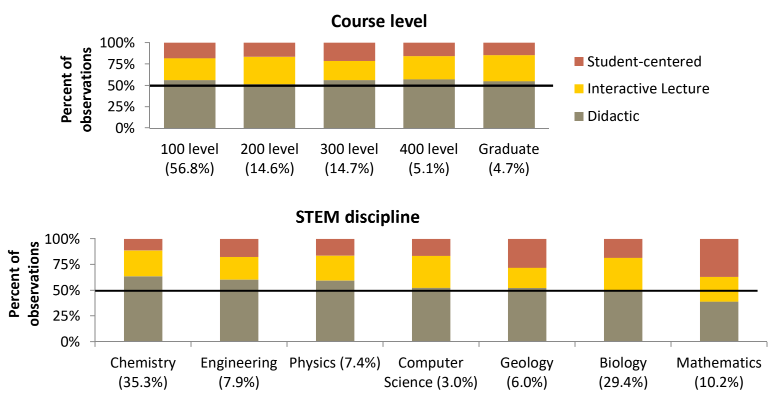
Minimal transformation was observed in the STEM curriculum

- Didactic teaching dominates across the curriculum and across STEM disciplines.



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Why is change not happening?

Discipline-Based Education Research Products

Student Learning Processes

POGIL

Instructional Materials

Pedagogies

Assessments

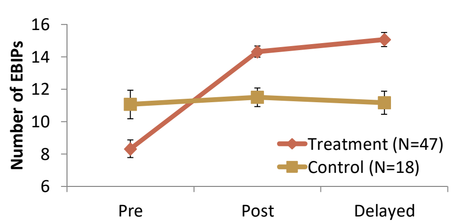
Gap

STEM Instructional Practices

DBER scholars have focused on R&D and dissemination

- The focus has been on leveraging research on student learning to develop, test, and disseminate new curricula and instructional practices.
- Dissemination increases awareness but not necessarily adoption of these products.

Awareness of evidence-based instructional practices

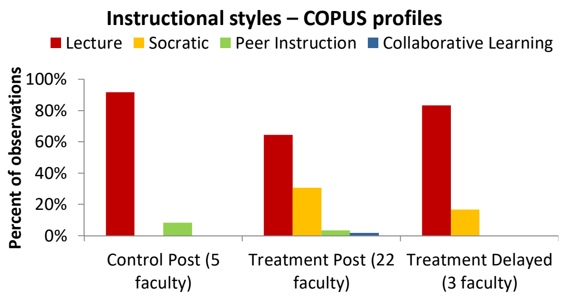


RESEARCH CORPORATION for SCIENCE ADVANCEMENT

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of research in science teaching*, *48*(8), 952-984.
Stains, M., Pilarz, M., & Chakraverty, D. (2015). Short and long-term impacts of the Cottrell scholars collaborative new faculty workshop. *Journal of Chemical Education*, *92*(9), 1466-1476.

In DBER, we have focused on R&D and dissemination

- The focus has been on developing, testing and disseminating through workshops new curricula and instructional practices.
- Dissemination increases awareness but not necessarily adoption of these products.



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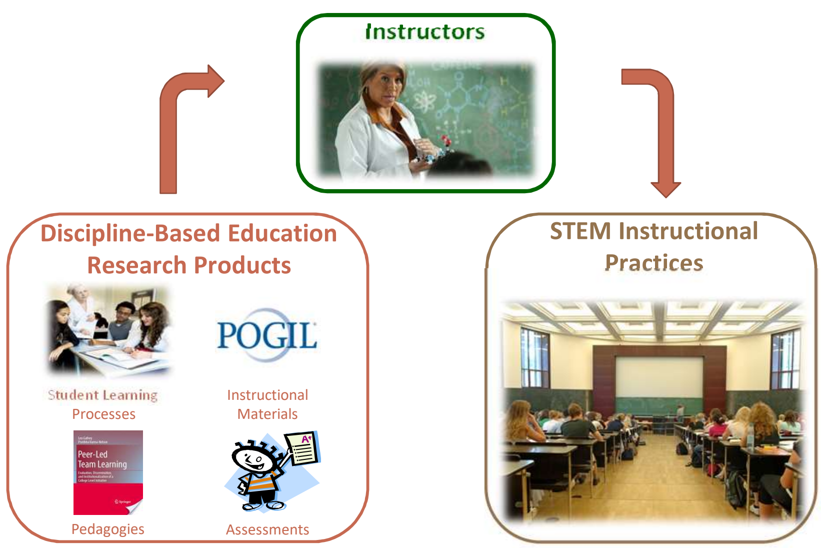
Stains, M., Pilarz, M., & Chakraverty, D. (2015). Short and long-term impacts of the Cottrell scholars collaborative new faculty workshop. *Journal of Chemical Education*, *92*(9), 1466-1476.

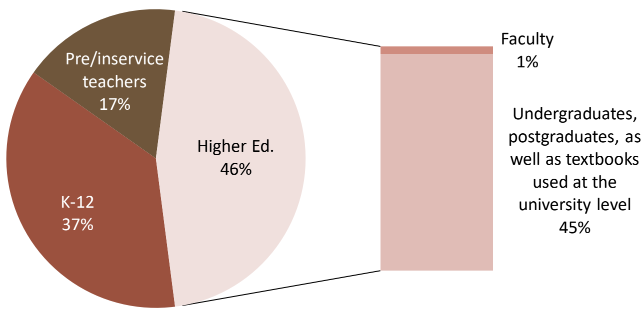
Instructors are the bridge between research and practice



Yet, we know little about faculty's thinking about teaching

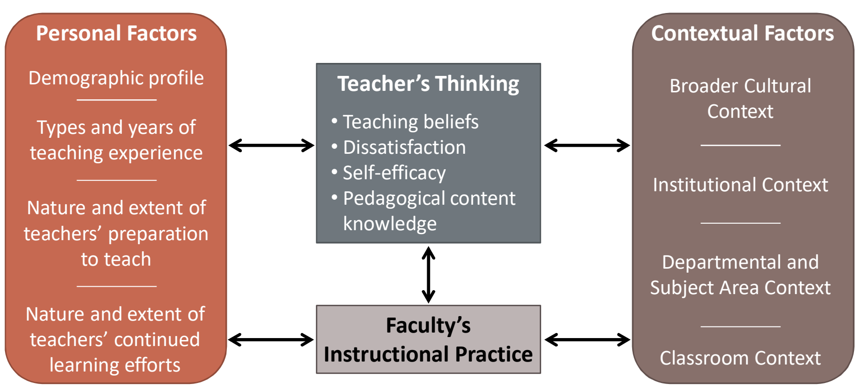
- Faculty-focused studies in chemistry education research have been limited.

Focus of CER studies (N=650; 2004-2013)



Teo, T. W., Goh, M. T., & Yeo, L. W. (2014). Chemistry education research trends: 2004–2013. *Chemistry Education Research and Practice*, *15*(4), 470-487.

Many factors impact faculty's instructional decisions



Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal*, *40*(3), 731-767.
Gibbons, R. E., Villafañe, S. M., Stains, M., Murphy, K. L., & Raker, J. R. (2018). Beliefs about learning and enacted instructional practices: An investigation in postsecondary chemistry education. *Journal of Research in Science Teaching*.

Illustrative example

- Collected surveys and classroom observations from a representative group of faculty from a chemistry, biology and physics department at one research-intensive institution.

	Pedagogical Experience	Attitudes toward student-centered teaching	Departmental norms toward student-centered teaching	EBIPs knowledge and use
Chemistry	**Limited**	**Negative**	**Weak**	**Knowledge: 62%** **Use: 11%**
Biology	**Moderate**	**Positive**	**Moderate**	**Knowledge: 65%** **Use: 19%**
Physics	**Extensive**	**Positive**	**Strong**	**Knowledge: 68%** **Use: 33%**

Lund, T. J., & Stains, M. (2015). The importance of context: an exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. *International Journal of STEM Education*, *2*(1), 13.

Promoting change is complicated

SCIENCE ADVANCES | RESEARCH ARTICLE

SOCIAL SCIENCE

Evaluating the extent of a large-scale transformation in gateway science courses

Rebecca L. Matz[1]*, Cori L. Fata-Hartley[2], Lynmarie A. Posey[3], James T. Laverty[4], Sonia M. Underwood[5], Justin H. Carmel[5], Deborah G. Herrington[6], Ryan L. Stowe[3], Marcos D. Caballero[7], Diane Ebert-May[8], Melanie M. Cooper[3]

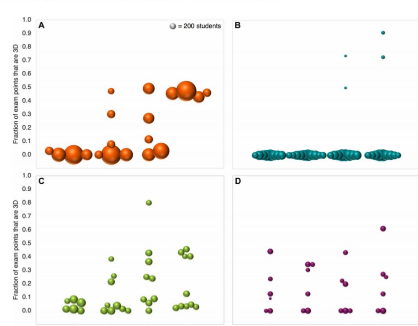
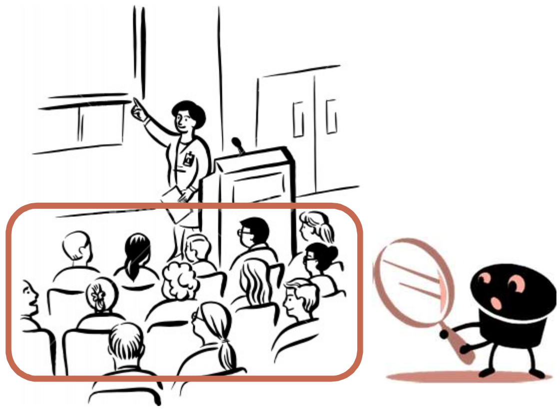


Fig. 1. 3D assessment items over time. Fraction of exam points that reflect the three dimensions over time in (**A**) Chem I and II, (**B**) Phy-A and Phy-C I and II, (**C**) Bio I, (**D**) Bio II. Each data point (bubble) represents either a final exam or, when the final exam was unavailable, two or more midterm exams. Each data point is scaled by

Matz, R. L., Fata-Hartley, C. L., Posey, L. A., Laverty, J. T., Underwood, S. M., Carmel, J. H., ... & Cooper, M. M. (2018). Evaluating the extent of a large-scale transformation in gateway science courses. *Science Advances*, *4*(10), eaau0554.

We need to understand our faculty



Science Faculty
= Discipline-Based Education Research Learners

Science Learners

We need to understand our faculty

Student-focused investigations

- Conceptual understanding and conceptual change
- Problem solving & Science and engineering practices
- Instructional strategies to improve STEM learning
- Metacognition
- Students' dispositions and motivations to study STEM

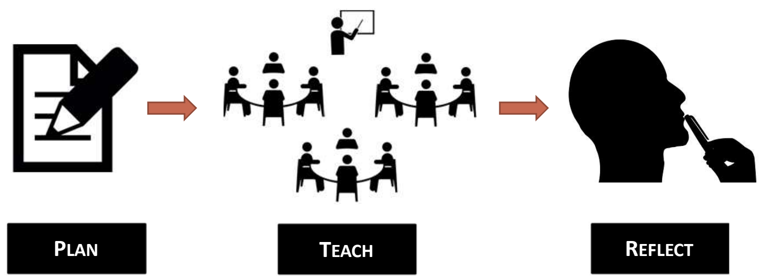
Faculty-focused investigations

- Conceptual understanding and conceptual change
- Instructional decisions and skills when planning and teaching
- Strategies to improve STEM teaching
- Reflective practice
- Faculty's dispositions and motivation to implement research-based instruction

National Research Council. (2012). Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering. S.R. Singer, N.R. Nielsen, and H.A. Schweingruber, Editors. Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press

Exploring faculty's instructional planning and reflections

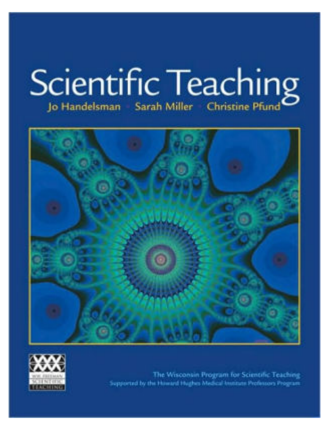
- Overall research question: How do STEM faculty plan the teaching of a week of content and how do they reflect on this experience?



Erdmann, R. & Stains, M. Exploring STEM postsecondary instructors' accounts of instructional planning and reflection in the context of the Scientific Teaching pedagogical framework. *Journal of Research in Science Teaching* (Accepted, under revision)

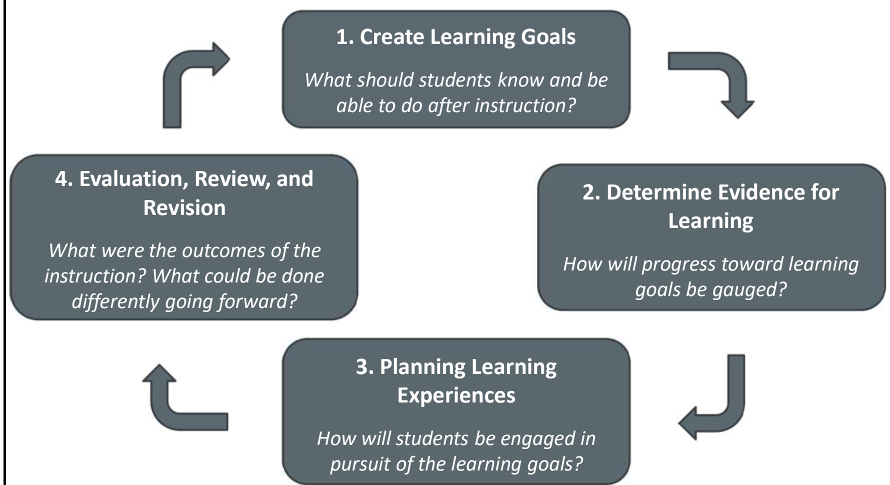
Scientific Teaching

- Key characteristics of Scientific Teaching:
  - A scientific teacher has explored the breadth of reasons why we teach science.
  - A scientific teacher evaluates learning regularly and makes teaching decisions based on evidence.
  - Scientific teaching is an iterative process of review and revision.
  - Active learning, assessment, and diversity are core themes of scientific teaching.



Handelsman, J., Miller, S., & Pfund, C. (2007). Scientific Teaching. New York: W.H. Freeman and Company.
Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., and Wood, W.B. (2004). Policy forum: scientific teaching. *Science* 304, 521–522.

Scientific Teaching Framework



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Research Questions

- What types of learning goals do postsecondary STEM instructors have for their students?
- How do postsecondary STEM instructors plan to assess achievement of learning goals?
- What learning experiences do postsecondary instructors plan to use to help students achieve the learning goals?
- To what extent are postsecondary instructors satisfied with their teaching?
- What types of revisions do postsecondary instructors plan to implement in the next execution of the course?
- What relationships exist between postsecondary instructors' level of satisfaction with their teaching and their intent for instructional change?

Erdmann, R. & Stains, M. Exploring STEM postsecondary instructors' accounts of instructional planning and reflection in the context of the Scientific Teaching pedagogical framework. *Journal of Research in Science Teaching* (Accepted, under revision)

Pedagogical Content Knowledge

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In Berry, A., Friedrichsen, P., & Loughran, J. (Eds.), *Re-examining pedagogical content knowledge in science education* (pp.28-42). New York, NY: Routledge.

Methods: Context

- Doctoral University – Highest Research Activity institution in the Midwest
- Evaluation of workshop series intended to teach STEM faculty about Peer Instruction and Just-in-Time Teaching

Scientific Teaching Workshop Series

NSF

DUE 1256003

Methods: Participants

Attribute		Percentage of instructors
Treatment Status	Control	26
	PI	43
	JiTT	31
Class Size	1 to 25	24
	26 to 50	19
	51 to 100	19
	101 through 150	12
	151 plus	26
Course Level	Lower Undergrad	62
	Upper Undergrad	24
	Graduate	14
Course Discipline	Biology	38
	Chemistry	24
	Math	10
	Physics	10
	Other (7 disciplines)	19
Experience (years)	0 to 6	21
	7 plus	79

Methods: Data Collection

- Data was collected before implementation of the workshop series.

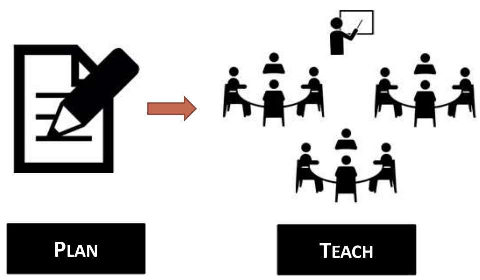
PLAN

Pre interview questions

1. What are your learning goals for students this week?
2. How do you plan on engaging students into the content? What specific teaching techniques do you plan to use in the class?
3. How do you plan to assess students' achievement of your learning goals?

Methods: Data Collection

- Data was collected before implementation of the workshop series.



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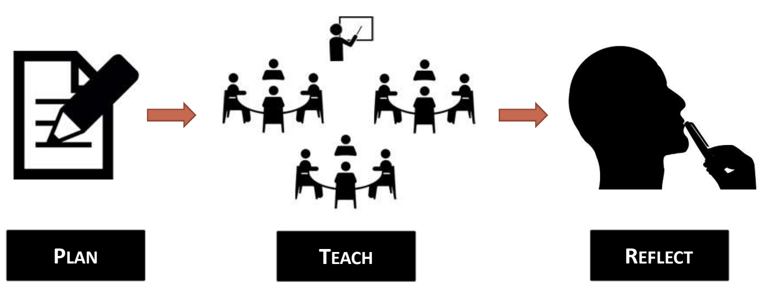


Post interview questions

1. To what extent did you meet your goals this week?
2. Did the students learn what you intended them to learn? How do you know?
3. Were you satisfied with students' engagement this week?
4. What would you do differently if you were to teach this class again?
5. To what extent were you satisfied with your teaching strategy this week?

Methods: Data Analysis

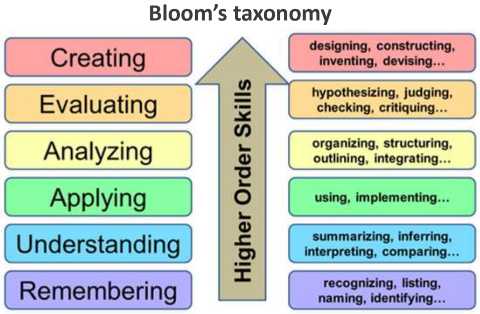
- All authors contributed to the development of the code book (~200 codes).
- Most codes emerged from the data through an iterative process.
- The unit of analysis was the instructor's full response to an interviewer's question.
- Five of the transcripts were coded by two authors.
- The mean pooled kappa value for the five transcripts was 0.864.
- Both authors coded the rest of the interviews independently.
- Code book was eventually reduced based on frequencies of codes. Final code book includes 49 codes.

Learning goals

1. Create Learning Goals
What should students know and be able to do after instruction?

- Learning goals should address core ideas, cross-cutting concepts, and scientific and engineering practices.
- Learning goals should engage students at various cognitive levels.

Bloom's taxonomy



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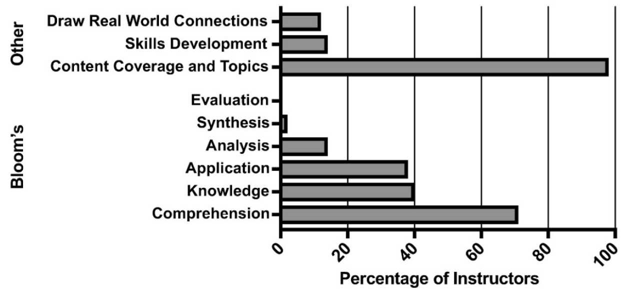
Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., … & Wittrock, M. C. (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, abridged edition. *White Plains, NY: Longman*.

Learning goals

1. Create Learning Goals

What should students know and be able to do after instruction?

- Most faculty (98%) answered the questions by listing topics.
- Most (88%) also provided goals that could be bloomed. Majority of those were at the lower cognitive levels.
- Results are consistent with other BER studies.



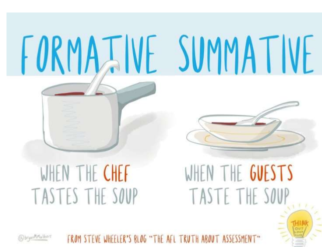
Derting, T. L., Ebert-May, D., Henkel, T. P., Maher, J. M., Arnold, B., & Passmore, H. A. (2016). Assessing faculty professional development in STEM higher education: Sustainability of outcomes. *Science advances*, *2*(3), e1501422.
Momsen, J.L., Long, T.M., Wyse, S.A., & Ebert-May, D. (2010). Just the Facts? Introductory Undergraduate Biology Courses Focus on Low-Level Cognitive Skills. CBE - Life Sciences Education, 9(4), 435-440.

Planned assessment

2. Determine Evidence for Learning

How will progress toward learning goals be gauged?

- Two main types of assessment are used:



- Research has demonstrated the positive impact on student learning of formative assessments.
- National reports advocate for wide implementation of formative assessments.

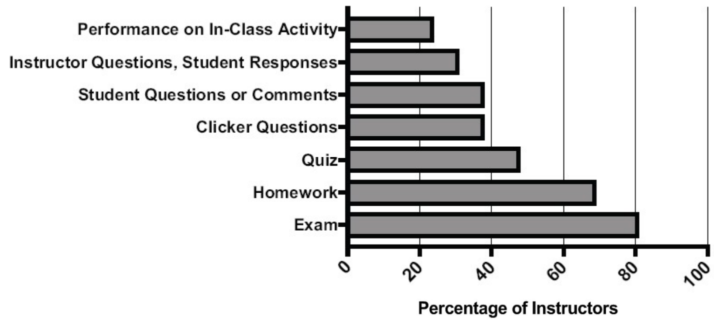
Dirks, C., Wenderoth, M.P., & Withers, M. (2014). Assessment in the college classroom. New York: W.H. Freeman and Company
National Research Council. (2003). Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics. Washington, D.C.: National Academy Press.

Planned assessment

2. Determine Evidence for Learning

How will progress toward learning goals be gauged?

- Summative assessments are more commonly used than formative assessments.

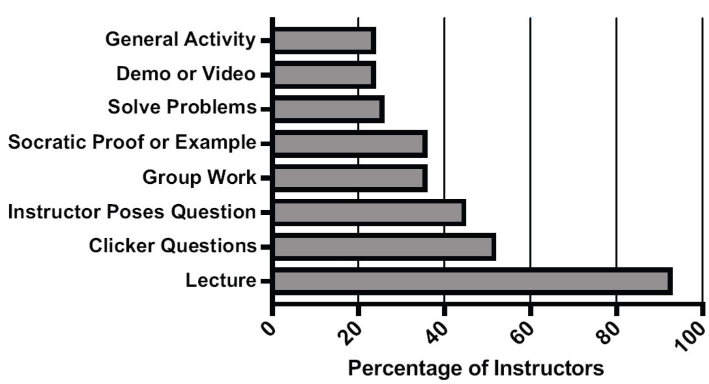


Learning experiences

3. Planning Learning Experiences

How will students be engaged in pursuit of the learning goals?

- Instructors use lecture and questioning mostly.
- 90% mentioned at least three engagement strategies, and 60% described at least four separate strategies.



Clickers highlight gaps in faculty's knowledge of assessment

- A fifth of the faculty thought of clicker questions as an engagement tool but not an assessment tool:

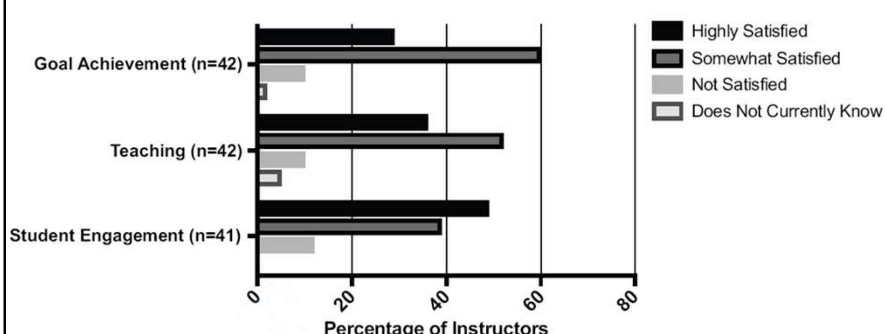
> "I don't really use clicker questions to assess their learning. [Students] use clicker questions to assess their learning, and I use my lecturing. I assess their learning on exams. I don't really care if they get the clicker questions right or not, as long as they are participating."
>
> Angela, a lower-level undergraduate biology instructor

Faculty are satisfied with instructional practices

4. Evaluation, Review, and Revision

What were the outcomes of the instruction? What could be done differently going forward?

- Faculty were in general satisfied with their week of teaching.
- The most satisfying aspect was student engagement.



Faculty use weak evidence to assess their satisfaction

Satisfaction with student engagement

Participation levels: 51%

Students' physical reactions: 34%

Attendance: 15%

"Whenever I teach one of these big introductory courses, the students are quite engaged, people aren't falling asleep and reading the [school newspaper] and so far they seem to be paying attention to me... You can look at the eyes of 150 students in a broad sweep, and if you just said something that doesn't resonate or sink in, you get this kind of average glazed over look of the whole class…The students are engaged enough that I can tell from the way they are looking at me, just the eye contact that I'm making in this big lecture format, whether they are getting it or not, the people seem to be quite engaged."

Clark, an experienced physics instructor

Faculty use weak evidence to assess their satisfaction

Satisfaction with teaching

Personal feelings: 43%

Student engagement: 36%

Assessment results: 12%

"Quite satisfied. Yeah, I think I gave a pretty good lecture for each time and I think the class and I get along quite well, so I was quite pleased with it."

"I was very satisfied... I mean, it can always be better, but with the amount of time I have, I think I use most of the tools that we have, like using the clicker, using the PowerPoint, using models to give students various ways to learn the same thing... I'm sure if someone else sees it, they might say this could be better, but I feel I've done my best."

Faculty are not clear about student learning

4. Evaluation, Review, and Revision

What were the outcomes of the instruction? What could be done differently going forward?

- About a third of the faculty did not know whether their students had learned.
- Another third had some evidence but were also waiting on the results of summative assessments.
- None of them say that students did not learn, even if some evidence pointed to the contrary.

> *"I really won't know until I give them the exam and at the exam time, I really don't go back and see who was actually in attendance and did well on the exam…"*
>
> Dwight, an instructor of a lower-level biology course

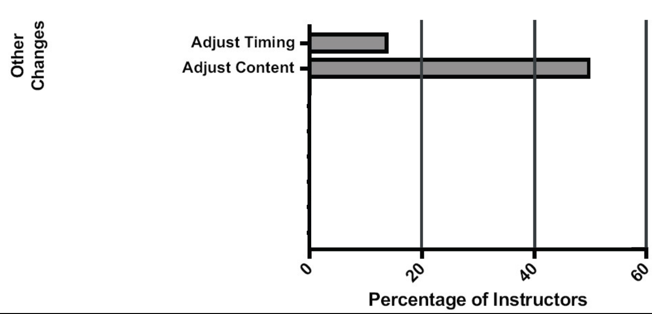
Faculty have plans to revise their course

4. Evaluation, Review, and Revision

What were the outcomes of the instruction? What could be done differently going forward?

- Most faculty identified specific aspects of their teaching they would change:
  - 51 % want to adjust content coverage

> "I would probably emphasize more of the basic chemistry… The point is, if I'm talking about enzymes, they should understand the protein structure. If I'm talking about membranes, they should know what a phospholipid is. You can understand the materials by reviewing the background of chemistry. So I'd probably emphasize that a bit more."



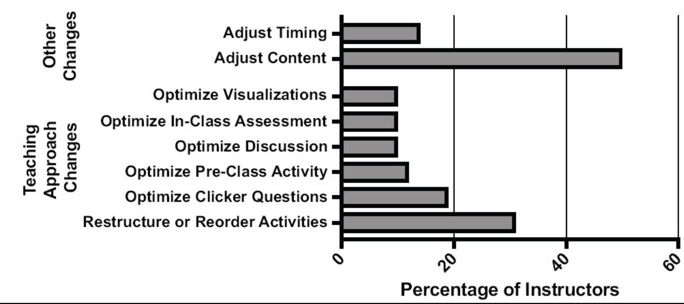
Faculty have plans to revise their course

4. Evaluation, Review, and Revision

What were the outcomes of the instruction? What could be done differently going forward?

- Most faculty identified specific aspects of their teaching they would change:
  - 51 % want to adjust content coverage
  - 73% want to change their approach to teaching

"I would probably skip the worksheet and give it to them as a homework. I felt that starting out with a worksheet was good in theory, they found it as hard as I hoped they would. I had hoped they would find it hard, but they found it really hard. So I probably would not have led in with that."



The relationship between satisfaction and change is complex

- Research has suggested that dissatisfaction is necessary although not sufficient for instructor to engage in instructional change.

Satisfaction with teaching

Satisfaction with goal achievement

Satisfaction with student engagement

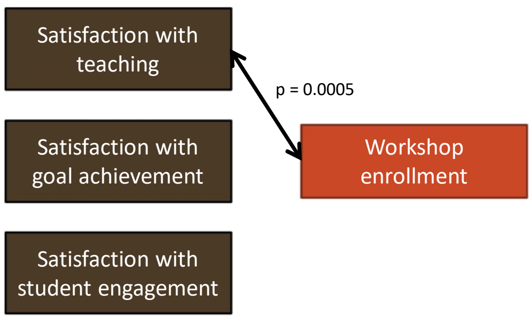
Workshop enrollment

Instructional revisions

Andrews, T.C., & Lemons, P.P. (2015). It's personal: Biology instructors prioritize personal evidence over empirical evidence in teaching decisions. CBE - Life Sciences Education, 14(1), 1-18.
Gess-Newsome, J., Southerland, S.A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. American Educational Research Journal, 40(3), 731-767.

The relationship between satisfaction and change is complex

- Only satisfaction with teaching was significantly related to enrollment in pedagogical workshop.

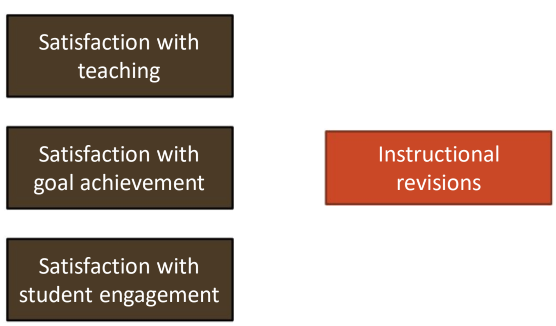


	Percent of highly satisfied
Did not enroll in either workshop	82
Enrolled in Peer Instruction	12
Enrolled in Just-in-Time Teaching	30

Andrews, T.C., & Lemons, P.P. (2015). It's personal: Biology instructors prioritize personal evidence over empirical evidence in teaching decisions. CBE - Life Sciences Education, 14(1), 1-18.
Gess-Newsome, J., Southerland, S.A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. American Educational Research Journal, 40(3), 731-767.

The relationship between satisfaction and change is complex

- None of the different types of satisfaction predicted instructional change.



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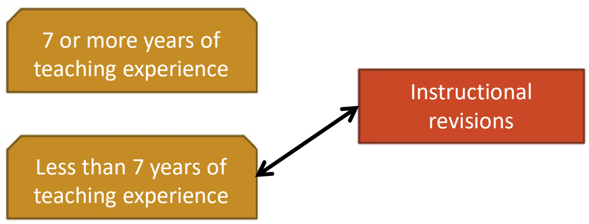
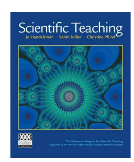
Teaching experience was the only predictor of instructional change

- Teaching experience level was significantly related to change in course content ($p < 0.0013$) and course goals ($p < 0.0004$).



STEM faculty weakly embody Scientific Teaching



Scientific Teaching

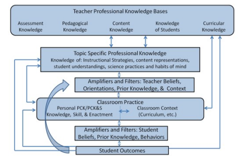
- A scientific teacher evaluates learning regularly and makes teaching decisions based on evidence.
- Scientific teaching is an iterative process of review and revision.
- Active learning, assessment, and diversity are core themes of scientific teaching.

STEM faculty

- Many faculty evaluate learning a few times a semester.
- Teaching decisions are based on weak evidence (i.e., personal feelings and student physical responses).
- Junior faculty are more likely to plan for revisions.
- Faculty mostly employ teacher-centric strategies and summative assessment.

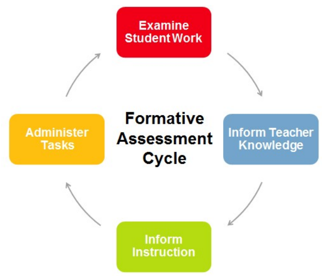
Andrews, T. C., & Lemons, P. P. (2015). It's personal: biology instructors prioritize personal evidence over empirical evidence in teaching decisions. *CBE—Life Sciences Education*, *14*(1), ar7.

STEM faculty have limited educational knowledge



- STEM faculty's instructional decisions are grounded in content coverage not students' learning outcomes.

- STEM faculty have limited knowledge of assessment and their role in informing their own practices.



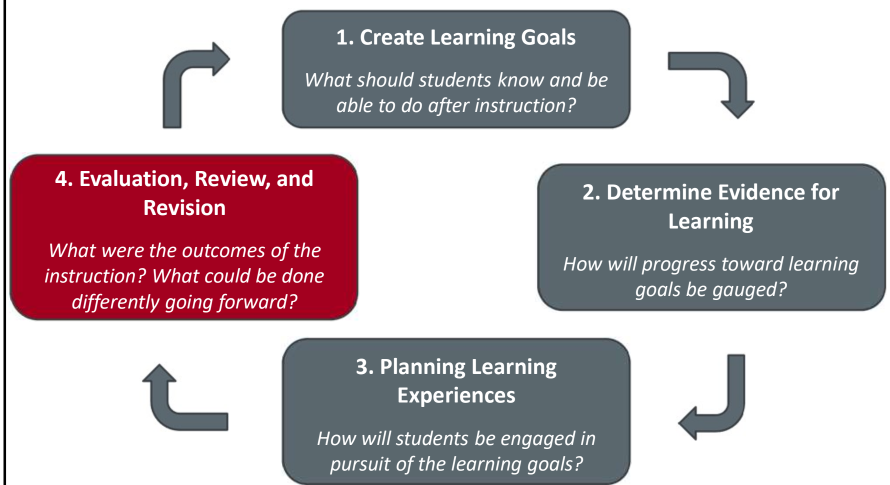
STEM faculty's teaching mindset is teacher-centric

- Results point to a self-centered mindset with limited considerations of student learning.

Topics and low level learning goals	Satisfaction with teaching	Teacher-centric strategies
Junior faculty	Evidence of confirmation bias	Summative assessment

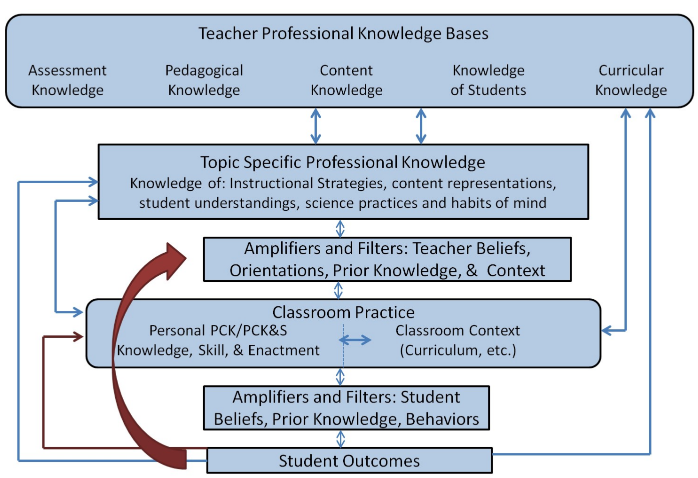
- Faculty's experiences as students and the environment at research-intensive institutions enforce this mindset.

Change strategies should focus on reflective practice



Change strategies should focus on promoting reflective practice

- We should not assume that reflections take place.



Change strategies should target personal empiricism

We assume your students don't learn so use this strategy.


PNAS

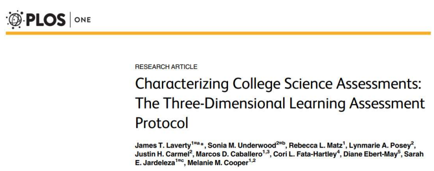
Active learning increases student performance in science, engineering, and mathematics

Scott Freeman[a,1], Sarah L. Eddy[a], Miles McDonough[a], Michelle K. Smith[b], Nnadozie Okoroafor[a], Hannah Jordt[a], and Mary Pat Wenderoth[a]

[a]Department of Biology, University of Washington, Seattle, WA 98195; and [b]School of Biology and Ecology, University of Maine, Orono, ME 04469

Edited* by Bruce Alberts, University of California, San Francisco, CA, and approved April 15, 2014 (received for review October 8, 2013)

To test the hypothesis that lecturing maximizes learning and 225 studies in the published and unpublished literature. The


PLOS | ONE

RESEARCH ARTICLE

Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol

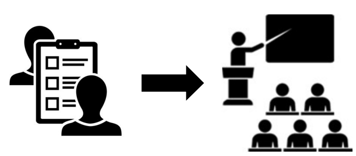
James T. Laverty[1¤a*], Sonia M. Underwood[2¤b], Rebecca L. Matz[1], Lynmarie A. Posey[2], Justin H. Carmel[2], Marcos D. Caballero[1,3], Cori L. Fata-Hartley[4], Diane Ebert-May[5], Sarah E. Jardeleza[1¤c], Melanie M. Cooper[1,2]

These assessments suggest my students are not learning; what should I change?

Andrews, T. C., & Lemons, P. P. (2015). It's personal: biology instructors prioritize personal evidence over empirical evidence in teaching decisions. *CBE—Life Sciences Education*, *14*(1), ar7.
Cooper, M. M., & Stowe, R. L. (2018). Chemistry Education Research—From Personal Empiricism to Evidence, Theory, and Informed Practice. *Chemical reviews*, *118*(12), 6053-6087.

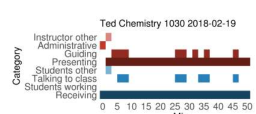
DBER needs to diversify studies on STEM faculty

- We need to study faculty in the wild, outside a reform effort.



- We need to characterize faculty's instructional decisions and value system.

- We need to identify how research-based analytical tools can promote reflections and actions.



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- Dr. Robert Erdmann


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