Research Question:

- ~~What are common features of methods/procedures that STEM departments have used to implement SoTL and research-based pedagogy into their departments?~~
- How can SToL inform the implementation of evidence-based teaching in STEM courses at the baccalaureate level?

Despite attempts to implement evidence-based instructional practices (EBIPs) in college classrooms, traditional lecturing persists as the most common way instructors lead their courses. Through this project I sought to explore, first more generally, how successful efforts of collegiate reform were structured. Then, I hoped to see how these ways of structuring change might inform successful long-lasting implementation of EBIPs in college classrooms. I found that successful change efforts should (1) have a clear understanding of the *theories of change* they are operating under, (2) use multiple change theories to simultaneously enact change at a variety of levels, (3) avoid using strictly enforced top-down approaches to change, and (4) be structured to engage with individuals over longer periods if possible. In terms of implementing EBIPs specifically, I found that (1) most change efforts in STEM are primarily focused on *diffusion innovations in EBIPs* and creating *communities of practice*, (2) suffer from lack of communication between the people developing EBIPs and the people implementing them, (3) should focus more on appealing to instructors' personal experiences than scientific evidence, (4) should support instructors through the process of implementing EBIPs, and (5) greatly benefit from institutional support to off-set the increased time-commitment and perceived pressure that people associate with implementing EBIPs.

Through most of the articles I surveyed, change agents implementing EBIPs in STEM tended to be partial to the implicit belief that EBIP implementation was positively (and strongly) correlated to having ample clear evidence of their effectiveness. This explains why a majority of change efforts in STEM focused on a diffusions of innovations approach, a theory of change that focuses on spreading awareness of EBIPs and their effectiveness. The diffusion of innovations approach begins tackling change at the individual level. This makes sense since top-down approaches to implementing EBIPs don't seem to be as effective (Borrego and Henderson 2014; Howson and Kingsbury 2023). However, a focus on surface level awareness building of EBIP effectiveness comes with several drawbacks. First, instructors' teaching decisions are primarily moved by personal experience, not empirical evidence (Andrews and Lemons 2015). Thus, awareness of EBIP effectiveness is rarely enough to persuade faculty to implement EBIPs. Second, general awareness of EBIPs is different from clear working knowledge of how to *effectively* implement them, which can lead to disillusionment and discontinued use among faculty who attempt implementation once (Henderson and Dancy 2008; Henderson 2005; Marbach and Rietschel 2016). Third, diffusion of innovations alone is not enough, since multi-pronged change efforts are more successful (Corbo et al. 2016; Reinholz et al. 2021; Kezar and Holcombe 2021), and lack of social or institutional support is one of the more common reasons why implementation goes un-attempted or is discontinued (Goodwin et al. 2018; Marbach and Rietschel 2016; Henderson 2005; Lund and Stains 2015).

The literature I surveyed also points to the fact that (perceived) departmental support and positive interactions with colleagues about EBIPs both aid in jumpstarting implementation and building resilience for their continued usage. This falls in line with the research calling for more multi-level approaches to change efforts. Luckily, building communities of practice (which include faculty learning communities) seems like another common change tactic STEM faculty. If structured correctly, these communities serve both as grounds to spread substantive knowledge of EBIPs and provide support for faculty implementing EBIPs.

Finally, there's something to be said about the importance of acquiring institutional support and funding to support the implementation of EBIPs. Some of the articles surveyed describe explicit steps to garner departmental support and shift departmental culture in favor of EBIPs (Corbo et al. 2016; Kezar and Holcombe 2021). Most of the case studies surveyed mention that additional institutional funding/support, along with other reward incentives, were useful to continue EBIP implementation.

Corbo, J. C., Reinholz, D. L., Dancy, M. H., Deetz, S., & Finkelstein, N. (2016). Framework for transforming departmental culture to support educational innovation. *Physical Review Physics Education Research*, *12*(1), 010113.

Following Adrianna Kezar's book *How Colleges Change*, the authors categorize change efforts into the following six "perspectives":

- Scientific management: restructuring reward systems drives change
- Evolutionary: adaptation to external factors drives change
- Social cognition: persuading rational actors drives change
- Cultural: appealing to existing or aspirational values drives change
- Political: internal power struggles and coalition building drives change
- Institutional: the influence of external powers drives change

each arising from a different *rationale*, an underlying belief of how change happens. This paper then argues that colleges are complex multi-leveled systems (they focus on three levels: faculty, department, administration), and that successful change efforts (specifically, the introduction of better teaching practices) should "target all these levels in a coordinated fashion". The paper gives concrete examples of change efforts in two departments, each attempting to change the multiple levels through a combination of efforts aligned with the various perspectives.

Following the author's arguments, we can explain why certain change efforts are ineffective when attempted in isolation. For example, attempting to improve education by enforcing new curricula is generally ineffective if fails to provide appropriate incentives to professors (scientific management) or engage with their beliefs (social cognition or cultural perspective).

Reinholz, D. L., White, I., & Andrews, T. (2021). Change theory in STEM higher education: a systematic review. International Journal of STEM Education, 8(1), 37.

The article surveys the literature for change efforts in STEM, and categorize them into "change theories". Change theories are characterized by their rationale (underlying ideas of how change happens), context (the relevant people, practices, climate, etc.), indicators (short term goals used to assess progress), and interventions (concrete steps being taken to achieve outcomes). The most common theories used in the articles surveyed were:

- Communities of practice (CoP): change centering small groups of people with a common interest working to develop engagement and common practices (these include faculty learning communities).
- Diffusion of innovations (DoI): change centering spread and adoption of ideas/practices
- Teacher-centered systemic reform (TCSR): change centering change in teachers, specifically through their relation with the larger departmental/university system.

The common themes found across the surveyed articles are (1) most change efforts focus on individuals, (2) fail to draw upon theory consistently or in-depth, and (3) theories as a whole are disjointed, too varied, and not used enough/consistently.

It seems to me that CoP and TCST had too much variation in indicators and interventions (and obviously context). Thus, as change theories, these were characterized only by the form the change effort took. Unfortunately, this looser might explain their popularity as theories in the survey.

Kezar, A. J., & Holcombe, E. M. (2021). Leveraging multiple theories of change to promote reform: an examination of the AAU STEM initiative. *Educational Policy*, *35*(6), 985-1013.

The AAU STEM Initiative was an initiative aiming to improve undergraduate STEM education at 8 research universities, while utilizing multiple approaches to change. This paper analyzes this initiative and draws conclusions about the successes and challenges when using of multiple theories. The paper begins by describing the approaches to change the AAU used:

- Systems Theory: understanding how an organization's (sub)systems are connected and driving change by coordinating them.
- Organizational Learning: treating an organization as an organism and focusing on the best ways to "teach" it.
- Network Theory: similar to diffusions of innovation, but focusing specifically on optimizing the networks through which information is shared.
- IT: similar to the institutional perspective, leveraging external influence to motivate change.

The bulk of the article describes a few activities the AAU STEM Initiative undertook as part of their project, and explains how each activity leveraged multiple theories of change.

Most of the theories and methods used by the AAU were focused at an institutional level and leveraged the AAU's influence, reputation, and funding to motivate change. Although the institutional approach seems a bit disconnected, it is important to remember that a majority of initiatives for change place the focus and onus on the mindsets of individual faculty members. Furthermore, most change initiatives focus only on maximizing the way in which they work

within currently established systems without actively trying to change them. So perhaps there are lessons to be learned from incorporating explicitly institutional/political theories of change into universities' internal change initiatives.

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.

The authors create a four categories of change typology by categorizing change efforts along two axes: (1) whether the change effort was focused on changing individuals or environments, and (2) whether the change effort had known goals, versus goals emerging during the change effort. Associated to each category is change strategy:

- Disseminating curriculum (individuals, known goal)
- Developing reflective teachers (individuals, emergent goal)
- Enacting policy (environment, known goal)
- Developing shared visions (environment, emergent goal)

The authors also categorized change agents into three communities of researchers:

- SER (discipline based, e.g. professors in certain departments)
- FDR (faculty development, e.g. people in centers for teaching)
- HER (higher education, e.g. people in administrative roles)

The paper found that (1) SERs, FDRs, and HERs each primarily focused on curriculum, reflective teachers, and policy, respectively, (2) multi-strategy change efforts and shared literature across the different groups and strategies was uncommon, (3) disseminating material and top-down enforcement are ineffective despite being the most popular strategies, (4) reports of success were overinflated when compared to the evidence backing the success, and (5) successful strategies tended to last longer periods, prioritized feedback and evaluation to instructors, and also focused on changing faculty member's conceptions.

The results of this paper are in line with the results from the first paper: more successful approaches to change tend to leverage existing beliefs and resources, and accompany material changes with corresponding mental/cultural shifts in instructors.

Borrego, M., & Henderson, C. (2014). Increasing the use of evidence-based teaching in STEM higher education: A comparison of eight change strategies. *Journal of Engineering Education*, *103*(2), 220-252.

This article expands on the four categories of change described above (curriculum, reflective teaching, policy, shared vision), presents a pair of strategies associated to each category, and discusses the underlying assumption/philosophy of each strategy. They also argue that most people only consider a single perspective when seeking change, but that coordinated change at multiple levels requires explicit descriptions and understandings of the different change initiatives.

Curriculum: These approaches rely on having a product ready to disseminate (e.g. teaching materials or classroom models). The key strategies here are diffusion and implementation. The main takeaway being that diffusion is important at early stages to raise awareness and convince instructors to try out strategies, but that success usually hinges on supporting instructors through appropriate training, performance evaluations, and feedback.

Reflective teachers: This is usually a bottom-up approach to change, relying on faculty motivation to enact change and usually excluding "resistant faculty". The two main strategies are SoTL/scholarly teaching and learning communities. The two strategies are best used in tandem, so that faculty seeking to alter their teaching to better fit with educational research also have support and perspective from other faculty.

Wise, S. B., Ngai, C., Corbo, J. C., Gammon, M. A., Rivard, J. K., Smith, C. E., ... & Corbo, J. C. (2022). Toward institutionalizing successful innovations in the Academy. *To Improve the Academy: A Journal of Educational Development*, *41*(1).

The writers of this article engage in action research, as they reflect on their experience working with the DAT (Departmental Action Team Project, a grant funded program designed to bring about department-level change related to undergraduate education). Their specific focus is on analyzing the institutionalization efforts of the DAT project. The authors identify seven "areas of effort" (team development, program design, program implementation, program assessment, awareness communication, outcomes communication, and financial stability) relevant to institutionalization efforts, and present strategies associated to each. My main takeaways, in the context of my research question, is some of the language used to describe departmental change (fast, slow, reactive, value driven, performance driven, etc.) and the idea that making change sustainable is what differentiates change from mere experimentation.

Kandiko Howson, C., & Kingsbury, M. (2023). Curriculum change as transformational learning. *Teaching in Higher Education*, *28*(8), 1847-1866.

This paper explores the effects of an attempt of curriculum reform at a UK institution, specifically focusing on the educational effects of the curriculum change, as well as the impact on the institution's culture. Their analysis measures how "engaged" (in terms of language, intent, or application) the changes in the curriculum were when compared to the intended values driving the new curriculum (assessment reform, active learning, diversity and inclusion, digital and technology enhanced learning). This article provides some data and evidence to the limitations of "top-down" approaches to change, or at least the limitation when aimed to be implemented through curriculum changes. I appreciate the authors separating the assessment of change into language, intent, and application, even though their findings showed a consistent drop of engagement when shifting from language to application.

Cox, M. D. (2004). Introduction to faculty learning communities. New directions for teaching and learning, 2004(97), 5-23.

This paper introduces and advertises the notion of a faculty learning communities (FLC). FLCs are small groups (8-12 people) of faculty members (or aspiring faculty) voluntarily working together on topics of teaching and learning through a period of 6-12 months. Communities can be topic-based (e.g. intra-departmental) or cohort-based (e.g. groups of junior faculty members). FLCs at Miami University reported increased student learning, higher chances of obtaining tenure, less stress/burnout, and a greater sense of community. FLCs were eventually implemented at several other institutions, which perhaps explains the popularity of the Communities of Practice change theory in the literature.

The appeal for FLCs, it seems to me, is the ease of implementation, and the ease of results/rewards, since most people volunteering to take part in them already care about either teaching or community building. Unfortunately, the article didn't discuss more guided ways to implement FLCs (e.g. to focus specifically on implementing evidence-based teaching) or guide more specific change. In that respect, FLCs seem less a direct tool for change, and more like a preliminary step to develop reflective teachers and slowly shift department cultures.

Cox, A. (2005). What are communities of practice? A comparative review of four seminal works. Journal of information science, 31(6), 527-540.

This paper traces the various definitions/usages of the term "communities of practice" through four seminal works. These communities are:

- Lave, Wenger (1991): groups of people socialized into an already established practice, though a process by which newcomers learn through participation, and help sustain the social processes upon which the practices are dependent.
- Brown, Duguid, (1991): informal groups of people with a shared job, collaborating to get the job done, even if it requires innovation and breaking away from established protocol.
- Wenger (1998): a group of people coming together through a common goal/work. Their distinguishing feature.
- Wenger, McDermott, Snyder (2002): informal groups within organizations aimed at collaboration and collective learning

This paper didn't say much of interest. In the conclusion, the author themselves state that the last definition is the one of dominant use, and the only one of interest for me.

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In An integrated approach to communication theory and research (pp. 432-448). Routledge.

This chapter describes several attributes of innovation and their role in the rate at which the innovation is adopted by a group. These attributes are:

- Relative advantage: whether the innovation is seen as better than what it is replacing.
- Compatibility: whether the idea is in line with already held values and structures.
- Complexity: the perceived difficulty of understanding or using the innovation.

- Trialability: whether the innovation can be (successfully) tried with on a trial basis.
- Observability: how visible the (results of the) innovation is to others

Unsurprisingly, all of these attributes are positively correlated with higher rates of adoption, except for complexity. The chapter also mentions previous research showing that rate of adoption is higher when it is individually chosen and optional (versus collectively chosen or mandated. Other factors influencing rate of adoption include the nature of the communication channels, the nature of the social system where the spread is taking place, and the extent and nature of the change agent's promotion efforts.

Although this chapter deals with innovations in general, I think the attributes serve as a good way of discussing diffusion of innovation (DOI) as a change theory. Other authors in the DOI literature seem to agree and cite his work often. Of course, in the context of university instructors' adoption new pedagogical practices, the perceived relative advantage of a new way of teaching is bifurcated into (1) whether it is advantageous to student learning or (2) whether it is advantageous to the instructors' own career.

Foote, K. T., Neumeyer, X., Henderson, C., Dancy, M. H., & Beichner, R. J. (2014). Diffusion of research-based instructional strategies: the case of SCALE-UP. *International Journal of STEM Education*, *1*, 1-18.

The authors study the factors that contributed to the successful spread of SCALE-UP (student-centered active learning environments with upside-down pedagogy) as a pedagogical strategy. Three properties they attribute to the success of SCALE-Up include (1) its flexibility and appeal across several disciplines (2) its support for instructor autonomy for implementation, and (3) the high observability that comes with SCALE-UP, since it requires renovation/redesigning classroom spaces. The authors also found that many early adopters of SCALE-UP learned and implemented it after interpersonal interactions with colleagues, suggesting it to be an effective strategy in terms of "getting the process started" at an institution. However, the authors also conjecture that SCALE-UP might be reaching a "tipping-point" (~16% adoption), and that DOI literature suggests change-agents should "change strategies" at this tipping point, to start appealing to a greater majority people. Finally, the authors found that implementations of SCALE-UP usually came with modifications. Using Rogers's language, this may pose a problem since such changes may affect the complexity, trialability, and relative advantage of SCALE-UP.

I think this case study provides great insight into the difficulty of spreading new research-based teaching strategies "past a certain point". In the case of SCALE-UP, a major roadblock in its widespread implementation is its need to redesign classroom spaces for it to be successful. This roadblock illustrates the need of change to occur and "several levels" on institutions. Most institutions have a few classrooms decentralized classrooms that would lend themselves to SCALE-UP, making it possible for a handful of individual instructors to experiment with it on a trial basis. However, more widespread implementation requires funding and institutional change.

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*, 1-21.

Of the ones I've read, this article is one of my favorites. The authors survey the levels of awareness, interest, and implementation of 17 evidence-based instructional practices (EBIPs) in the biology, chemistry, and physics departments of one research institution.

Surprisingly, the authors found a similar level of awareness of the EBIPs across all three departments, with all three reporting that their awareness came from interacting with colleagues within their own department. This is in line with the previous articles' findings that diffusion is effective at the individual/inter-personal level. Surveys in the article show how department culture affects the rate of interest in EBIPs. Departments with weaker norms surrounding student-centered and reported less interest in EBIPs. The opposite was true of departments with stronger norms. Finally, individual beliefs affected the rate at which EBIPs were actually adopted. Less experience and exposure to EBIPS, along with negative attitudes about student-centered learning, results in lower rates of adoption.

Along with the previous articles, this paper paints a vague picture of what successful implementation of EBIPs in a department might look like. Start by spreading general awareness of EBIPs, supporting a few instructors in successfully implementing them, getting opinion leaders to work on shifting department culture towards more positive views surrounding EBIPs, and then start tackling institutional level reforms needed for widespread implementation.

Marbach-Ad, G., & Hunt Rietschel, C. (2016). A case study documenting the process by which biology instructors transition from teacher-centered to learner-centered teaching. *CBE—Life Sciences Education*, *15*(4), ar62.

This is a case study of how two biology instructors at a research university transitioned from teacher-centered to student-centered teaching. Like the previous article, the authors use the innovation-decision model (Rogers 2003, adapted by Andrews and Lemons in 2015) to journey the instructor's transition. This decision model breaks down the process of adopting innovation into four stages: (1) knowledge, learning of the innovation, (2) persuasion, being convinced to use it, (3) implementation, trying out the innovation, and (4) reflection, deciding whether to continue use or drop back down to knowledge. The five attributes of innovation mentioned above characterize the persuasion stage of the innovation-decision model.

The results of the case study were a bit bleak, from the instructor's perspective. Their first attempt had more drawbacks than strengths, and even though their second attempt was a lot better, it took a huge amount of time and energy from instructors and teaching assistants, still had a lot of resistance from students, and still ultimately had to "compromise" the amount of material covered.

The challenges faced by these instructors mostly serve to show the importance of administrative and institutional support in the implementation of EBIPs. Successful (lasting) implementation of EBIPs require more funding, release time, training, manpower, and facilities.

Henderson, C. (2005). The challenges of instructional change under the best of circumstances: A case study of one college physics instructor. *American Journal of Physics*, *73*(8), 778-786.

This is another case study, following a tenured faculty member teaching 2nd semester physics at a research university. Like the previous paper, the professor encountered several difficulties while trying to implement EBIPs, which become the focus of this paper.

The main impediments to successfully implementing EBIPs for this professor were (1) an implicit educational theory that constrained his instructional choices, (2) general awareness of EBIPs without specific knowledge of instructional techniques, (3) overtly optimistic and intense planning, and (4) perceived external constraints (e.g. need to cover material) being prioritized over new instructional plans.

There is a lot to say about all these impediments (I'll focus on the first two). The first point is rather interesting. Just like change efforts have underlying theories of change (you have ideas of how change work in order to come up with something you think will enact change), instructional change efforts have underlying theories of how learning works. The second point is very important, since many change efforts focus on developing reflective teachers, but a developing a general sense of care is different from training people in specific instructional practices. The authors also noted that the professor never fully implemented known instructional practices without heavily altering them.

One of the suggestions in the paper is focusing on only a few changes at once. Of course, this only applies to more permanent faculty positions, but it seems like a good way of persuading more resistant department members, since this paper and the previous one show that trying to implement drastic change doesn't seem to go well for people that haven't had prolonged exposure and training in EBIPs.

Henderson, C., & Dancy, M. H. (2008). Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations. *American Journal of Physics*, *76*(1), 79-91.

This paper focused on the discrepancy between instructors who, to some extent, make decisions based on educational research, and the lackluster influence these decisions have on actually changing their teaching practices. The main conclusion the authors draw is that education researchers expect their models to be adoption with minimal changes, while instructors expect researchers to fit their EBIPs into their specific instructional environments. A

common theme in the failures of implementation can be summarized as *imperfect reinvention of EBIPs due to isolation*. In the interviews, instructors got defensive and felt undervalued, and perceived education researchers as being overly dogmatic. As a result, instructors mainly implemented EBIPs in isolation and only incorporated some aspects of reform ideas, rejected others, or reinvented ideas to fit their own educational theories or instructional practices. The results of this paper are in line with the previous two case studies.

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.

The authors of this paper interviewed 17 biology instructors who sought to implement case studies as an EBIPs into their biology classrooms. Their found that, at every step of the innovation-decision model, instructors primordially relied on their personal experience to inform their opinions and decisions about teaching. Even at the knowledge/persuasion stages, 16 of 17 participants admitted they were not particularly informed about of the empirical evidence supporting the effectiveness of case studies before they were convinced to try it out. The convincing was mainly attributed to personal experiences and interactions with colleagues (e.g. the instructors were recruited at a professional development conference focused on case study teaching in science courses).

The main takeaway from this paper is that it's more effective to target instructors' feelings when both advertising and implementing EBIPs. This includes implementing EBIPs specifically so that instructors have a better chance to *feel* like the EBIP is being effective.

Goodwin, E. C., Cao, J. N., Fletcher, M., Flaiban, J. L., & Shortlidge, E. E. (2018). Catching the wave: Are biology graduate students on board with evidence-based teaching?. *CBE—Life Sciences Education*, *17*(3), ar43.

This paper focuses on the experience of biology graduate students' journey through the innovation-decision model when it comes to adopting EBIPs. The paper confirms several of the ideas stated before. First, though there is a general awareness of EBIPs, and graduate students generally have positive associations of their impact, their general awareness does not equate to specific knowledge about EBIPs, or the empirical evidence justifying their effectiveness. The knowledge stage was also riddled with experiences of mandatory teaching trainings that did little to inform students of EBIPs. Very few graduate students reach the implementation stage of the decision model.

The focus on graduate students in this paper is quite interesting. Specifically, the graduate students have less control over their teaching, fewer opportunities to teach, less experience teaching in general, and inadequate exposure to EBIPs via their programs' mandatory trainings. They also reported little (perceived) support from their departments and faculty members if

implementing EBIPs. These are the same factors that keep showing up when researchers describe the failure of EBIP implementation.

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179-211.

This is more of a psychology article. The author focuses on how intention guides behavior, and focuses on the idea of perceived behavioral control, how able the individual feels that they can act in a certain way. The author postulates three factors that determine intention, which in turn determines action. These are: (1) attitude, how (un)favorably the subject views the action, (2) subjective norms, the perceived social pressure to engage in the action or not, and (3) perceived behavioral control.

In terms of EBIPs, the three factors influencing intention align with the ways in which change efforts should be structured in order to move instructors from the persuasion stage to the implementation stage of the innovation-decision model.

Froyd, J. E., Henderson, C., Cole, R. S., Friedrichsen, D., Khatri, R., & Stanford, C. (2017). From dissemination to propagation: A new paradigm for education developers. *Change: The Magazine of Higher Learning*, *49*(4), 35-42.

The authors of this paper call for a shift in the diffusion paradigm (i.e. the current way that the diffusion of innovation change strategy is commonly implemented). They suggest that, rather than trying to optimize awareness raising and data collection about efficacy of EBIPs, change agents should focus on making their EBIPs more widely applicable, while also working with potential users to customize the EBIPs into specific contexts.

The idea that more widely applicable EBIPs could be diffused more easily is supported by the SCALE UP case study, which is adaptable since it's not discipline-specific. The idea that education researchers should work in tandem with instructors to implement EBIPs is supported by the various case studies we've seen, to avoid instructors reinventing EBIPs and losing their efficacy.