

Change as a Scientific Enterprise: Practical Suggestions about Using Change Theory

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ABSTRACT

Change theory has increasingly become an area of scholarship in STEM education. While this area has traditionally been a topic for organizational psychology, business management, communication studies, and higher education, STEM education researchers are increasingly aware of the need to use formal theories to guide change efforts and research. Formal change theory encompasses our current research-based knowledge about how and why change occurs, and therefore, can guide the selection and design of promising interventions. Yet learning about and using theory is challenging because many of us have no formal training in this area and relevant scholarship comes from many different disciplines. Inconsistent terminology creates an additional barrier. Thus, this essay aims to contribute to a common lexicon in STEM higher educational change efforts by clearly distinguishing between formalized change theory, which emerges from research, and a theory of change, which guides the logic of a specific project. We also briefly review the current state of the field regarding the use of formal change theory and provide examples of how change theory has been used in biology education. Lastly, we offer practical guidance for researchers and change agents who wish to more intentionally and effectively use change theory in their work.

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education research has made impressive strides over the past few decades in demonstrating empirically that changes to teaching and learning environments can improve student outcomes (e.g., Chi and Wylie, 2014; Eddy and Hogan, 2014; Deslauriers *et al.*, 2019; Dewsbury *et al.*, 2022). Yet the use of evidence-based educational strategies remains less common than traditional approaches (e.g., Stains *et al.*, 2018). Thus, a key challenge that we face in biology education is achieving widespread improvement to students' educational experiences and outcomes. Knowing *what* to change and *how* to change are fundamentally different questions. Our discoveries about what we need to change in teaching and learning environments will have limited impact until we better understand how to achieve and maintain change within the complex system of STEM higher education.

For this reason, STEM education researchers are turning toward educational change as a scholarly area. This work often draws on other fields, such as organizational psychology, business management, communication studies, and higher education, and can encompass multiple levels, including networks, organizations, cultures, and individuals (e.g., Kezar, 2014). Scholars in the specific context of STEM education can use formal change theories from other disciplines to guide and study change efforts (e.g., Reinholz *et al.*, 2019; Hill, 2020; Archie *et al.*, 2022; DeMarais *et al.*, 2022; Viskupic *et al.*, 2022). However, numerous projects to transform STEM higher education have not taken advantage of formalized change theory, and therefore are

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not leveraging nor building upon what is already known about how to achieve change (see e.g., Reinholz *et al.*, 2021). We believe that this results from the fact that there are fundamental barriers to learning about and using change theory. This essay aims to take one modest step in reducing those barriers, so that individual projects and our field as a whole can more effectively achieve change and advance knowledge.

The intended audience for this essay includes both change agents and change researchers in biology education. Change agents are those who design and lead efforts to change some part(s) of the STEM higher educational system. Change researchers are those who systematically investigate change processes and outcomes, either by studying a specific change initiative or part(s) of the system relevant to change. An individual may hold one or both of these roles. We will argue that formal change theory is important to the work of both.

To begin, we briefly review two of our earlier works – distinguishing formalized change theory and a project-specific theory of change (Reinholz and Andrews, 2020), and a systematic review of STEM higher education change work (Reinholz *et al.*, 2021) – to set the stage for the current essay. From there, we look specifically at how change theory has been taken up in biology education research, highlighting some promising examples of what the field can do. Next, we offer a concrete set of suggestions that researchers and change agents can use at any stage of their work, alongside resources for further guidance.

CHANGE THEORY AND THEORY OF CHANGE

Change is a word that is often used informally in everyday language and most people have an intuitive understanding of the concept of change. Yet, to promote the scientific enterprise of leading and studying change, we need formal definitions and approaches. There is an entire lexicon related to change, including ideas such as a logic model, theory of action, pathway model, theory of change, change theory, and so forth. These terms take on a variety of meanings and are not used consistently across contexts and texts. With that in mind, this essay aims to contribute to a common lexicon in STEM higher educational change efforts and research. We focus on two specific

concepts that we believe are critical to catalyzing change: *theory of change* and *change theory*. Though these terms are nearly identical, they refer to two distinct, but related ideas (Table 1).

A theory of change is a tool created and used by a project team to articulate their desired outcomes and the mechanisms for achieving those outcomes (Anderson, 2005). It is a tool for those who are aiming to make a change, and results from team members continually coming together to agree upon specific goals that a project is trying to accomplish, how it is trying to accomplish the goals, and how to the team will know when they have achieved their goals (Table 1). This process raises important questions, surfaces assumptions and implicit ideas about how change occurs so they can be questioned, aids in developing a realistic plan, builds consensus, and helps a team communicate with stakeholders and funders (Anderson, 2005). A theory of change is something that a team can rely upon throughout its work to provide a north star to return to when the project gets off track. A project's theory of change is often revised in response to new data, new awareness of the literature, and shifting assumptions. The process of creating and refining a theory of change has its roots in evaluation work, and became popularized by activists working on community change. We encourage readers to refer to “The Community Builder's Approach to Theory of Change: A Practical Guide to Theory Development” by the Aspen Institute (Anderson 2005), to learn more.

A project's theory of change consists of a long-term outcome, preconditions, indicators, interventions, context, and underlying rationales/assumptions (Anderson, 2005). In many ways, a theory of change is similar to a logic model, but it is slightly less rigidly defined, and includes more information. Within a theory of change, the *long-term outcome* is the big picture goal that a project is trying to achieve, while the *preconditions* can be thought of as intermediate outcomes that are necessary to reach that larger goal. The *indicators* are the signs or tools of measurement that would allow a team to know that project outcomes are being achieved. The *interventions* are the things a team is trying to do to reach those outcomes, and the *rationales/assumptions* define underlying ideas about the context,

TABLE 1. Distinctions between theory of change and change theory

	Definition	Developers and scope	Key resources
Theory of change	A tool created, used, and revised by a project team to articulate their desired outcomes and the mechanisms for achieving those outcomes, make underlying assumptions explicit, and communicate with stakeholders.	Developed by the team leading a change project (i.e., change agents). Focused narrowly on one change project. Rarely disseminated.	Guides for creating a theory of change as part of project planning, implementation, and evaluation: Anderson (2005) University of Kansas Center for Community Health and Development (2018)
Change theory	A formalized framework of ideas, supported by evidence, that explains some aspect of change.	Developed by researchers, typically based on multiple change efforts, often in the disciplines of social sciences, business, or higher education. Generalized to be applicable beyond a single project or context, and disseminated accordingly.	Systematic review of the use of change theory in STEM higher educational change: Reinholz <i>et al.</i> (2021) Guide for using change theory from across disciplines to understand, lead, and enact change: Kezar (2014) ^a

^aKezar (2014) is a valuable synthesis because it describes groups of change theories, which could be thought of as schools of thought on how change occurs. Note that the book is about formalized change theories, but uses the terms “theories of change” and “change theories” synonymously, which does not align with the lexicon we propose in this essay.

how change works, how or why interventions will lead to pre-conditions, etc. These components of a theory of change are often articulated in a diagram to provide a roadmap describing what a project is trying to do and why change agents think it will work. Since a theory of change largely serves the project team, often they are not disseminated. We recommend two examples from STEM higher educational change: an open-source book chapter by Ngai *et al.* (2020) and an LSE Methods Essay about building a theory of change (which the authors refer to as a pathway model) by Reeves *et al.* (2020).

A change theory has a different scope and purpose than a theory of change (Table 1). A change theory is a formalized framework of ideas, supported by evidence, that explains some aspect of change and is meant to be applicable beyond a single context or project (Reinholz and Andrews, 2020). There are a wide variety of formal theories that could be relevant to change in STEM higher education, including theories that focus on different levels of change (e.g., individual change, cultural change, organizational change, network change). These theories have been developed, tested, and refined in diverse disciplines. Change theories provide theoretical frameworks to inform change efforts and change research. Theoretical frameworks provide a particular lens with which to view a social phenomenon (Luft *et al.*, 2022), and using a different change theory brings attention to different components of change. See Luft *et al.* 2022 to learn more about the role of theoretical frameworks in biology education research, especially if you find yourself grappling with how the term “theory” is used differently by scholars of education than by scholars in the sciences.

Change theory can inform the work of change agents and change researchers. We will illustrate this with one of the most commonly-used change theories in STEM higher education, the diffusion of innovations change theory. This change theory was developed by scholars in communication studies who aimed to characterize the process by which people decide to adopt a new innovation, such as a new irrigation method or a new form of contraception (Rogers, 2010). The full theory articulates stages of adoption that an individual experiences, characteristics of an innovation that influence adoption, prior conditions that influence adoption, and types of knowledge that support effective adoption among adoptees (Rogers, 2010). This change theory has been tested repeatedly across contexts, including in STEM higher education, and has explanatory power regarding individual change (e.g., Rogers, 2010; Foote, 2016).

Change agents have used the diffusion of innovations to guide interventions. In engineering, a team used this change theory to inform how they supported faculty in replacing lecture with a classroom workshop that included problem-solving tasks and collaborative learning. The change team considered the prior conditions and planned multiple interventions to shepherd faculty through the stages of adoption successfully (Pundak and Rozner, 2008).

Change researchers have also used the diffusion of innovations extensively. Guided by this formalized change theory, researchers have studied the specific stages of faculty adoption of evidence-based teaching strategies, (e.g., Henderson, 2005; Lund and Stains, 2015), the prior conditions that facilitated or hindered changes to teaching strategies (e.g., Marbach-Ad and Hunt Rietschel, 2016), innovation characteristics that made teaching strategies more and less likely to be adopted

(e.g., Foote *et al.*, 2014), and the consequences that arose when faculty lacked particular knowledge (Foote, 2016). Change researchers have also advanced our understanding of how to achieve change using this theory, by suggesting how the theory should be extended, tailored, and reimagined for the context of STEM educational change (e.g., Henderson and Dancy, 2008; Andrews and Lemons, 2015; Froyd *et al.*, 2017).

Here we described how projects used a single change theory, but often projects will benefit from more than one change theory because the changes we seek in STEM higher education challenge the status quo and occur within a complex system (Kezar, 2014). For an example of how project activities can draw on multiple change theories, see Kezar and Holcombe (2021). This study of an AAU project suggests that thoughtfully using multiple change theories to guide an initiative brings needed attention to the hierarchical structure of higher education, and has the potential to save time, money, and human resources (Kezar and Holcombe, 2021). Relatedly, not every change theory is useful in every context. Change agents and researchers should carefully consider their goals and context in determining which formal change theories provide useful framing for their work.

Part of the persistent confusion between project-specific theory of change and formalized change theory may result from the fact that they are often used together. Change theories can, and should, inform a project’s theory of change because change theories encompass research-based knowledge about how change occurs and what impacts the change process (e.g., Kezar, 2014; Reinholz and Andrews, 2020). Using change theory to inform how a project is carried out allows change agents to draw on the existing evidence and knowledge about achieving change, rather than relying solely on the project team’s lived wisdom about achieving change. Change theory can guide how change agents think about the context in which they seek change, help change agents question assumptions they hold about what promotes change, and help the team fully articulate the rationales that connect the interventions they plan to the goal they aim to achieve (e.g., Kezar *et al.*, 2015; Reinholz and Andrews, 2020). For example, a common implicit assumption is that STEM faculty will be convinced to change their teaching when they encounter robust evidence of how a new teaching method improves student outcomes. This idea seems sensible because we consider scientists to be logical decision-makers who value evidence. A change team that held this assumption might design a workshop that engaged faculty in reading and discussing research papers on evidence-based teaching. However, faculty often do not make teaching decisions based on scientific evidence (e.g., Andrews and Lemons, 2015). A change team that relied on the diffusion of innovations change theory might instead plan interventions that aimed to elicit dissatisfactions that instructors had with traditional lecture-dominated approaches to teaching; convey the relative advantages of evidence-based strategies, with specific attention to the elicited dissatisfactions; create opportunities for instructors to vicariously experience the strategies; and guide instructors through a process of trying and revising their use of the strategies (e.g., Rogers, 2010; Andrews and Lemons, 2015; Marbach-Ad and Hunt Rietschel, 2016). This is just one example of how using a formal change theory could support a team in designing an intervention that is based in evidence

about what promotes change, and therefore more likely to have the intended impact.

Given the complexity of systemic change at the levels of departments, universities, and society, change theories are not prescriptive. A change theory will not describe exactly how to achieve change in a given context. Nonetheless, they do help explain how and why change works, and can provide useful guidance for change agents and researchers. Crucially, when used to inform a project's theory of change, a change theory can help generate testable hypotheses about how change occurs, which is a fundamental requirement for knowledge generation through the scientific process. Unless change researchers are able to use formalized change theory in an intentional way to guide their work, it is difficult to enact change that uses and builds upon our collective knowledge via scientific inquiry.

This section has laid out the lexicon that we hope will bring much-needed clarity to the area of theory in educational change work. However, we caution readers that the field does not yet use these terms consistently. For example, in the current program solicitation for the Improving Undergraduate STEM Education from the National Science Foundation (NSF 23-510, 2023), proposers are asked to “include one or more theories of change to guide the proposed work.” It is unclear whether NSF expects a theory of change for the individual project, whether they expect researchers to draw on formalized change theory to inform their work, or whether they expect both. As another example, Adrianna Kezar (2014), a higher education scholar and leader in STEM educational change research, uses the terms change theory and theory of change interchangeably (e.g., Kezar and Holcombe, 2021). Her work has much to offer change agents and researchers, and we encourage readers to use her book “How Colleges Change” as a resource for learning about groups of change theories and how they can be usefully applied by change agents, while keeping in mind the different uses of these important terms. Within our discipline-based education research community, where many of us have come to this work after our formal training in other disciplines, inconsistent terminology creates unnecessary challenges as we try to learn from and contribute to change efforts and scholarship. With this in mind, we strongly advocate for consistent distinctions and clear definitions.

SYSTEMATIC REVIEW OF CHANGE THEORIES

Previously, we systematically analyzed the use of formalized change theory in the growing body of STEM higher education change research (e.g., Reinholz *et al.*, 2021). Initially, we set out to understand the generalizable knowledge that STEM higher education research has produced, but quickly realized that it was difficult to make any generalized claims because of the fragmented nature of the literature. The systematic review included 191 articles published from 1995–2008 as covered by a prior systematic review (Henderson *et al.*, 2011), and 12 articles that came up from a reverse citation search. We collected an additional 206 articles between 2008–2019 through a variety of databases and by scouring individual journals for relevant papers. From the corpus of 409 papers, we found that only 97 met the inclusion criteria of: (1) being situated in STEM higher education and (2) using formal change theory (rather than just talking about change in an atheoretical way).

The review had a few key findings (Reinholz *et al.*, 2021). First, we found that the majority of research focused on individual change, and paid less attention to changing the organizations and systems of higher education. Second, we found that many articles relied on a shallow use of change theory. Change theory was often briefly reviewed in the introduction of a paper, or used for a small part of the analysis, but it was not used holistically in a way that would inform the design, data collection, and analysis of the project. Consequently, change theory was rarely used to generate and test hypotheses, which is at the core of building knowledge through the scientific process. Third, we found that research was theoretically disjointed with a striking use of 40 different change theories across 97 articles. Only two theories – diffusion of innovations (Rogers, 2010), communities of practice (Lave and Wenger, 1998) – were used in more than six articles. This is a huge barrier to making connections between the findings of different studies of change in STEM higher education. Studies that use different change theories often attend to and measure different things or conceptualize of similar things in different ways, leaving readers with the challenging work of trying to understand the ways in which findings from one context are relevant in a different context.

This systematic review made an important contribution in highlighting the growth in change-oriented research, as more recent research drew on formal change theories more regularly and with more diversity. At the same time, change theory was often applied in a post hoc way and used shallowly. As change agents and researchers ourselves, we have personally grappled with the challenge of using formal theory to inform our interventions and of conducting robust change research. Yet, unless we take up this challenge, the resources and time invested in change interventions and change research may fall short of the ultimate goal of informing widespread and meaningful change because what we learn in one project is difficult to compare across projects and therefore, does not advance our collective knowledge.

In our own ongoing development as researchers, we have benefited from opportunities to learn about the scholarship of change via formalized change theory and to engage with examples of educational change initiatives that use and contribute to change theory. Therefore, we will next present and discuss examples of the use of change theory in biology education, including how scholars have usefully relied on change theory to inform interventions and research, and how the practical recommendations we describe below might have been applied to these examples.

PROMISING EXAMPLES OF CHANGE RESEARCH IN BER Change Theory Can Guide Interventions

One role that change theory can play is to inform the interventions that a project uses to foster change. Formal change theory enables change agents to move beyond the implicit ideas about change that we have each developed as a result of our lived experiences, and instead rely on empirically-grounded theory about how or why change occurs. Change theory can inform a variety of aspects of the change process, including setting goals, recognizing important parts of the context and culture that must be considered, developing interventions, and finding levers for change within the system (Reinholz *et al.*, 2021). Here we summarize the ways in which one biology education reform initiative relied on change theory.

PULSE is a nonprofit organization that is committed to providing departments with skills, training, and support required to help meet the goals outlined in Vision and Change (AAAS, 2011). PULSE began in 2012, and over more than a decade it has continued to develop and refine its approach. As a part of this process, it continues to take up more ideas from change theory in productive ways. For example, PULSE has grounded workshops on fostering departmental change in systems thinking, a change theory from the field of organizational change. Systems thinking is one component of systems theory (Senge, 2006), and deals with how the components of a system are interrelated and how they influence one another. Cause and effect may be complicated and decoupled in complex systems; competing priorities are ubiquitous; and change agents must consider the system as a whole, unintended consequences, the role of time, and the impact of underlying beliefs on the system (Stavrianeas *et al.*, 2022).

Systems thinking informed the work of PULSE in several ways. First, a key rationale underlying the work of PULSE is that achieving widespread life sciences education reform requires organizational change because faculty work within complex systems and their behaviors are influenced by the system (DeMarais *et al.*, 2022). Second, PULSE workshops aim to equip teams of faculty and administrators to enact departmental change by teaching them about systems thinking. In pre-workshop preparation and throughout a 3-d in-person workshop, PULSE facilitators supported participants to learn to think about their departments as systems. Specifically, they learned to use systems thinking “habits of mind” as scaffolding for making sense of their individual contexts, goals, and actions plans (DeMarais *et al.*, 2022). Third, researchers investigated the extent to which participants developed systems thinking knowledge and applied this to their change efforts (Stavrianeas *et al.*, 2022).

The work of PULSE provides a valuable example of how systems thinking can be used as a change theory to plan interventions to support organizational change. Previously, only three papers had grounded their work in systems theory (Reinholz *et al.*, 2021). Future work would similarly benefit from considering change theory that speaks to the complex system of higher education.

This example also creates an opportunity to consider how the work of PULSE might further benefit from and contribute to change theory. Given the complexity of the PULSE interventions, the project might have relied on multiple change theories that addressed different parts of the systems they aimed to change. In addition to systems thinking, Stavrianeas *et al.* (2022) relate their work to the four frames theory, which describes four components of organizational culture that must be attended to in pursuing change (e.g., Bolman and Deal, 2008; Reinholz and Apkarian, 2018). However, it is not clear whether and how this change theory informed PULSE interventions. One could imagine using four frames to guide interventions with departments, as meaningful departmental change likely requires actively working within each frame. The work of the PULSE team also could have contributed to change theory by transparently explaining how the use of systems theory served their work and the ways in which it was not particularly helpful. Such a discussion could inform whether and how other change agents used systems thinking,

thereby advancing our collective work to determine *how* to achieve change.

Change Theory Can Guide Research on Change Initiatives

Another key role for change theory is to guide research investigating change interventions or parts of the system that are important to the intended change. Researchers can apply formalized change theory to inform the questions they ask, data collection and analyses, and the interpretation of findings. Since change theories have largely emerged from other fields, it is especially valuable when researchers discuss how a change theory accurately predicted findings or how the findings suggest the need to tailor the theory to the context of STEM higher education change.

By drawing on change theory in their work, researchers take into account what has been learned in prior research about how or why change occurs, setting up their own work to build upon and refine existing knowledge. When research about change does not consider formalized theory, it makes it difficult for researchers to synthesize discoveries across papers and projects. Since many change projects are context-specific, they operate like a study of $n = 1$. It is only when we can connect findings across contexts that there is potential to learn more generalizable lessons about enacting and maintaining meaningful change in STEM education. An analogy can be found in meta-analyses of quantitative research findings, which are a powerful tool for identifying trends and uncertainty across many studies (Garg *et al.*, 2008). A meta-analysis can be conducted when the authors of each individual paper provide key information, including the sample size, mean differences between groups, and measures of variation. Similarly, in STEM educational change, we will be better able to draw conclusions across studies when particular comparable information is reported by researchers. Grounding our work in the same change theory can facilitate this process because researchers drawing on the same theory will be more likely to measure and report on similar constructs. In this way, formalized change theory can act as the bridge that links together otherwise siloed reform efforts. The research community may additionally need to define key pieces of information that allow comparisons to be made across change studies. Here we summarize two examples of research in biology education that used change theory. Together they illustrate ongoing and future researchers can increase the impact of their work by using and advancing change theory. In these examples, change theory informed the research, not a change intervention.

Example 1. Matz and Jardeleza (2016) used a change theory and a relevant typology in a study of leadership in a biology education change initiative at one university. The change theory they used, referred to as “The Austin Model,” takes a systems perspective, placing faculty and their instructional decisions within the context of their department, institution, and other relevant external contexts (Austin, 2011). This change theory defines components of institutions that can be levers or barriers to faculty changing their teaching: reward systems, professional development, leadership, and work allocation (Austin, 2011). In addition to this change theory, which aims to explain how or why STEM faculty change their teaching, they used a typology of change strategies described in

Henderson *et al.* (2011) and Borrego and Henderson (2014). This is an organizing framework of different strategies to achieving change that has two dimensions: the focal unit of change (individuals vs. environments and structures) and the nature of the intended outcome (prescribed vs. emergent). This typology, called “Four Categories of Change Strategies,” is not a change theory, but has been useful to a variety of projects pursuing change because it brings order to a wide array of strategies one might use to achieve change.

Matz and Jardeleza (2016) drew heavily on the Austin model and Four Categories of Change Strategies typology (hereafter Four Categories typology) to inform their data analyses and interpretations. Specifically, they conducted qualitative content analysis using *a priori* codes based on the Austin model and Four Categories typology. They next developed themes based on their detailed coding and continued to rely on the Austin model and Four Categories typology to make sense of the data. Their reliance on the models is evident in the findings, and they offer insights about the utility of the model and typology to their work in the discussion.

This paper provides an example of how researchers can use change theory as a lens that guides their data analysis and interpretation. When future change researchers use the Austin model or Four Categories typology, they will be able to make clear connections between their research questions and findings and the work of Matz and Jardeleza (2016), thereby taking a vertical step in our collective knowledge about organization change and leadership in STEM departments. One additional approach this work might have taken is specifically testing hypotheses derived from the Austin model, which specifies components that can act as barriers or levers to change. Hypothesis testing can then lead to fine-tuning a change theory to better match the observed data.

Example 2 Goodwin and colleagues (2018) used the diffusion of innovations change theory in a study of biology graduate students’ adoption of evidence-based teaching strategies (Rogers, 2010). Because this theory has been widely used (Goodwin *et al.*, 2018; Reinholz *et al.*, 2021) could build on prior work rather than reporting results that were difficult to connect to the existing literature. These researchers used part of the diffusion of innovations change theory in their data analyses. This change theory describes five stages that individuals progress through as they consider and try adopting an innovation. After inductive coding to provide fine-grained characterizations of graduate students’ experiences and perceptions of evidence-based teaching, Goodwin *et al.* (2018) made holistic judgements using full interviews about the stage of innovation adoption that was most descriptive of each participant. Their results report the number of participants who had progressed to each of the five stages, which is similar to an approach taken by a prior study in physics education (Henderson *et al.*, 2012). By using the diffusion of innovations change theory, this research advanced our collective knowledge about change in STEM higher education.

There may be a few ways that these researchers could take their use of change theory even further. Given that the diffusion of innovations model has been used repeatedly in STEM higher educational change, it would be appropriate to

move toward testing hypotheses that are grounded in the theory about what attributes of the instructors, the intervention, and the environment are accelerating or stalling adoption of evidence-based teaching strategies. Taking this approach would have required drawing on more aspects of the diffusion of innovations theory, in addition to the stages of change, and might have revealed additional and useful insights about graduate students’ progression toward evidence-based teaching. Given the coherent use of the theory to frame the research and to analyze and interpret the data, Goodwin *et al.* (2016) were additionally positioned to relate their findings back to the theory, including the ways in which the change theory accurately predicted their findings and the ways in which it fell short. The findings of one study can better contribute to our broader understanding of *how* change occurs when the findings are explicitly connected back to the original theory and to other studies that have drawn on the same theory.

PRACTICAL SUGGESTIONS FOR LEADING AND RESEARCHING CHANGE

Thus far, we have discussed the role and importance of change theory for change projects and research, and considered promising examples of how theory has been used in biology change work. From our perspective, drawing on change theory is an ongoing learning process, in which all members of our research community have room for growth. Although we strongly advocate for change agents to rely on formalized change theory from the offset of a project, even if a project is underway, it is not too late to consider how change theory can support it. Here, in Table 2, we provide a list of practical suggestions and resources, including exemplars, for advancing the use of change theory by those leading change and those studying change in biology education. The resources and exemplars that we offer are not exhaustive but rather are meant to provide a productive starting place. Alongside the table, we describing each suggestion in greater detail in text. These ideas may be relevant across STEM disciplines.

The practical suggestions that we offer are grounded in our experience as change agents and researchers and also from our professional roles as part of the Accelerating Systemic Change Network (ASCN). As leaders of an open working group for those interested in change theory, we have spent the past few years professionally exploring how to support others to learn more about change. Much of the advice we offer here is grounded in that practical experience.

Learn About Change Theories

Change agents and researchers can engage in ongoing learning about change theories that might be relevant to their work, much like scholars in any discipline stay abreast of literature in the field. From our experience, it is challenging to discover relevant theories, because they come from a variety of siloed disciplines. Fortunately, there are an increasing number of resources that describe, review, and synthesize change theory for the specific context of STEM higher education. The breadth of relevant literature can be intimidating, so we recommend starting by identifying and exploring just a few change theories that seem most relevant to your research question or change effort. The review and synthesis

TABLE 2. Suggestions for the use of change theory in interventions, research, and dissemination, for change agents and change researchers. The paragraphs in this section elaborate on the suggested resources

Target audience	Suggestion	Resources
Change agents and change researchers	Learn about change theories that are potentially relevant to your work.	Short (1–2 page) change theory summaries, written for a lay audience. ASCN: Accelerating ASCN. (2023) Do you need a change theory? https://ascnhighered.org/ASCN/change_theories/index.htm Kezar, A. (2013). <i>How colleges change: Understanding, leading, and enacting change</i> . Routledge. New York, NY. Reinholz, D. L., White, I., & Andrews, T. (2021). Change theory in STEM higher education: A systematic review. <i>International Journal of STEM Education</i> , 8(1), 37. https://doi.org/10.1186/s40594-021-00291-2 López, N., Morgan, D. L., Hutchings, Q. R., & Davis, K. (2022). Revisiting critical STEM interventions: a literature review of STEM organizational learning. <i>International Journal of STEM Education</i> , 9(1), 39. https://doi.org/10.1186/s40594-022-00357-9 Morton, T. R. (2022). Critical race theory and STEM education. In Oxford Research Encyclopedia of Education. Oxford University Press. https://doi.org/10.1093/acrefore/9780190264093.013.1614
Change agents and change researchers	Build capacity for change expertise on your projects.	Find collaborators and resources through the ASCN: Promoting knowledge development to support institutional change in higher education. https://ascnhighered.org/index.html .
Change agents	Create a theory of change with your project team.	Anderson, A. (2005). <i>The Community Builder's Approach to Theory of Change: A Practical Guide to Theory Development</i> . Aspen Institute Roundtable on Community Change. (accessed August 4 2023). www.theoryofchange.org/pdf/TOC_fac_guide.pdf University of Kansas Center for Community Health and Development. (2018). <i>Community Toolbox: Developing a logic model or theory of change</i> . https://ctb.ku.edu/en/table-of-contents/overview/models-for-community-health-and-development/logic-model-development/main Ngai, C., J. C. Corbo, G. M. Quan, K. Falkenberg, C. Geanious, A. Pawlak, M. E. Pilgrim, D. L. Reinholz, C. Smith, and S. Wise. (2020) "Developing the Departmental Action Team theory of change." Chp 5 in White <i>et al.</i> (Eds). <i>Transforming Institutions: Accelerating Systemic Change in Higher Education</i> . Pressbooks. https://doi.org/10.7275/4tn1-4w61 Reeves, P. M., Bobrownicki, A., Bauer, M., & Graham, M. J. (2020). Communicating complex STEM program evaluation to diverse stakeholders. <i>CBE—Life Sciences Education</i> , 19(2), es4.
Change agents	Revisit your project's theory of change using the data you collect (regularly).	See above: Anderson (2005); University of Kansas Center for Community Health and Development. (2018)
Change researchers	Draw upon existing change theories rather than creating your own.	Examples of papers using existing change theory: Andrews, T. C., & Lemons, P. P. (2015). It's personal: Biology instructors prioritize personal evidence over empirical evidence in teaching decisions. <i>CBE—Life Sciences Education</i> , 14(1), ar7. https://doi.org/10.1187/cbe.14-05-0084 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. <i>CBE—Life Sciences Education</i> , 15(4), ar62. https://doi.org/10.1187/cbe.16-06-0196 Reinholz, D. L., Ngai, C., Quan, G., Pilgrim, M. E., Corbo, J. C., & Finkelstein, N. (2019). Fostering sustainable improvements in science education: An analysis through four frames. <i>Science Education</i> , 103(5), 1125–1150. https://doi.org/10.1002/sce.21526 Hill, L. B. (2020). Understanding the impact of a multi-institutional STEM reform network through key boundary-spanning individuals. <i>The Journal of Higher Education</i> , 91(3), 455–482. https://doi.org/10.1080/00221546.2019.1650581 Kezar, A., & Holcombe E. (2021). Leveraging multiple theories of change to promote reform: An examination of the AAU STEM Initiative. <i>Educational Policy</i> , 25(6), 985–1013. *Note that this paper is about change theories, as defined in this LSE essay, not a project's theory of change Archie, T., Hayward, C. N., Yoshinobu, S., & Laursen, S. L. (2022). Investigating the linkage between professional development and mathematics instructors' use of teaching practices using the theory of planned behavior. <i>Plos one</i> , 17(4), e0267097. https://doi.org/10.1371/journal.pone.0267097 Viskupic, K., Earl, B., & Shadle, S. E. (2022). Adapting the CACAO model to support higher education STEM teaching reform. <i>International Journal of STEM Education</i> , 9(1), 1–20. https://doi.org/10.1186/s40594-021-00325-9

(Continued)

TABLE 2. Continued

Target audience	Suggestion	Resources
Change researchers	Use change theories to generate testable hypotheses.	See above: Hill (2020); Archie <i>et al.</i> (2022) Kezar, A., Gehrke, S., & Bernstein-Sierra, S. (2018). Communities of transformation: Creating changes to deeply entrenched issues. <i>The Journal of Higher Education</i> , 89(6), 832–864.
Change researchers	Connect change theory coherently throughout a paper.	See above: Matz & Jardelez (2016); Marbach-Ad & Hunt Rietschel (2016); Goodwin <i>et al.</i> (2018); Reinholz <i>et al.</i> (2019); Hill (2020); Kezar & Holcombe (2021); Archie <i>et al.</i> (2022); Viskupic <i>et al.</i> (2022)
Change researchers	Relate findings back to change theory to confirm, tailor, or critique the theory in the context of STEM higher education.	See above: Andrews & Lemons (2015); Kezar <i>et al.</i> (2018); Hill (2020); Viskupic <i>et al.</i> (2022) Henderson, C., & Dancy, M. H. (2008). Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations. <i>American Journal of Physics</i> , 76(1), 79–91. https://doi.org/10.1119/1.2800352 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. <i>Change: The Magazine of Higher Learning</i> , 49(4), 35–42. https://doi.org/10.1080/00091383.2017.1357098 Reinholz, D. L., & Apkarian, N. (2018). Four frames for systemic change in STEM departments. <i>International Journal of STEM Education</i> , 5(1), 1–10. https://doi.org/10.1186/s40594-018-0103-x

articles in Table 2 provide an easy on ramp for learning about change theory (Kezar, 2014; Reinholz *et al.*, 2021; López *et al.*, 2022; Morton, 2022). Once you have learned of a few potentially relevant change theories, you might want to learn more about them. Diving deeper into these theories might involve reviewing the original sources, examining how the change theories have been applied in similar contexts, and considering how they might be adapted or combined to fit the specific needs and goals of your research project. The ASCN website has a collection of brief summaries of change theories for STEM higher education. They are written for those new to a change theory and point toward avenues for digging deeper into theory when you want to learn more (ASCN, 2023a)

Build Capacity for Change Expertise

The field of biology education research is ultimately about change. Though a researcher might study student thinking, identity development, or course-based research experiences, the downstream applications of the research almost always require changes in teaching, mentoring, programming, practices, and more. With this in mind, it is worth considering how to learn about change. What learning opportunities do change agents and change researchers on your project need to develop necessary knowledge and skills for enacting and/or studying change? What does “change education” look like in your project? One way to build capacity is to seek out collaborations with other researchers or organizations who have specific expertise in organizational change or higher education. This can provide your team with access to new perspectives, resources, and expertise that can help to strengthen their own capacity for change.

Another way to build capacity is to seek ongoing “change education” for your team. This can involve regular training sessions, workshops, or seminars on relevant topics related to change theories, data collection, analysis, and interpretation.

As a starting place, we encourage readers to connect with the ASCN, which hosts resources, working groups, workshops, and a biannual conference on systemic change in STEM higher education (ASCN, 2023b).

Create a Theory of Change for Your Project

As described above, creating a project-specific theory of change is a useful consensus-building process that can help a change agent team uncover implicit assumptions and come to a common understanding of goals and how to approach change. When creating a theory of change, it is important to determine the unit of change and the long-term and short-term goals of change. The unit of change can vary depending on the specific project and can include students, instructors, departments, disciplines, institutions, or networks. Next, the long-term and short-term goals of the project should be identified. Long-term goals may include creating a more inclusive and equitable learning environment, increasing student retention and success, equipping instructors to use inclusive teaching, or changing institutional policies and practices. Short-term goals may include implementing new pedagogical strategies in core courses, increasing awareness and understanding of diversity and inclusion among faculty, or characterizing faculty perceptions about institutional practices. It is important to ensure that the goals of change are realistic and measurable, and that they align with the overall purpose of the project. Once the goals have been identified, the change team can develop a roadmap to outline the steps needed to achieve the desired outcomes. This roadmap should be flexible and allow for adjustments as necessary based on ongoing evaluation and feedback. To get more information about how to create a theory of change, see Anderson (2005) and University of Kansas Center for Community Health and Development (2018). Reeves *et al.* (2020) provides guidance for developing and communicating a theory of change, which they refer to as a “pathway

model” and includes examples in an LSE Methods Essay. To see another example of a theory of change in STEM higher education, see Ngai *et al.* (2020).

Revisit Your Project’s Theory of Change

Systemic change takes a long time (many years), and throughout the process of implementing and studying change, new lessons are learned that may shift the initial assumptions that guided a project. As such, revisiting your project’s theory of change is a crucial step in any research project. This allows change agents to assess whether the goals and strategies outlined in the theory of change are being met and whether any adjustments are needed. The process of revisiting the theory of change should involve a discussion among change agents and a review of the data collected. Revising a theory of change regularly (e.g., once a year) helps ensure that the project remains on track and to identify any potential issues that need to be addressed (e.g., Anderson, 2005). It is essential to be open to modifying the theory of change as needed to ensure that the project continues to be effective and relevant. This review process can be very generative as it provides an opportunity to surface underlying assumptions, shifting priorities, and to make sure the team is aligned on practical and research goals. The review process may also point toward the need for additional formalized change theory to inform or explain the interventions, the impact of context on the interventions, and the rationales connecting interventions and outcomes. For example, if the interventions are not having the intended impact, relevant change theories may help reveal why and point toward revised or different interventions. To get more information about how to create and revisit a theory of change, see Anderson (2005) and University of Kansas Center for Community Health and Development (2018).

Draw Upon Existing Change Theories Rather Than Creating Your Own

Drawing upon existing formalized change theories can help you ground research in a broader context and build upon the work of others. Whereas each project would develop its own theory of change, it is generally not necessary for a project to create new change theory. A project’s theory of change outlines key goals, the interventions meant to reach those goals, the rationale for why and how the interventions will achieve the goals, and the local context. In contrast, a change theory is more formalized and meant to describe generalizable knowledge about how or why change occurs across contexts. While no change theory is perfect, a variety of theories can be tailored to your project by applying them to your context. We caution readers that developing an entirely new formalized change theory may only be useful to the field if no relevant theory relates to the project (although this is unlikely). In most cases, synthesizing, building upon, or tailoring existing change theories will more readily advance knowledge in the field. This intellectual work uses existing knowledge and brings together ideas from disparate fields, whereas creating a new change theory that is not situated within the existing literature generates ideas disconnected from the web of what is already known. In addition to the examples summarized above, these papers provide examples of ways that research-

ers draw on change theory in STEM higher education change: Andrews and Lemons, 2015; Marbach-Ad and Hunt Rietschel, 2016; Reinholz *et al.*, 2019; Hill, 2020; Kezar and Holcombe, 2021; Archie *et al.*, 2022; Viskupic *et al.*, 2022.

Use Change Theories to Generate Testable Hypotheses

It is important to use change theories to generate testable hypotheses, as this allows for a systematic and rigorous approach to research. Given the complexity of changing systems and the wide body of research that is already out there, generating more disconnected studies does not contribute deeply to our collective body of knowledge. Comparatively, by using formalized change theories to guide hypothesis generation, researchers can ensure that their questions are based on a solid foundation of existing knowledge and are more likely to produce meaningful results that can be used to contribute to and extend existing knowledge. This also enables researchers to speak back to change theory from their results, by showing how their findings support, refute, or extend existing theories. Here are two examples: Hill, 2020; Archie *et al.*, 2022.

Connect Theory Throughout a Paper

Connecting change theory throughout a research paper is crucial for providing a strong theoretical foundation and ensuring that the research is grounded in a coherent framework (e.g., Luft *et al.*, 2022). We urge change researchers, whenever possible, to intentionally plan for how they will use formalized change theory to guide and shape the research questions, data collection methods, data analysis, and interpretation of results. By doing so, the study will have a stronger foundation and be better positioned to contribute to the existing body of knowledge. Many projects will ultimately rely on multiple change theories and the need for a particular theory may emerge as a project progresses. We encourage those leading change and researchers to be flexible and adaptive in how they use change theory as a tool to further their work. At the same time, we posit that, if our change research is to advance collective knowledge about achieving meaningful change, we must plan and conduct our own efforts using change theory. The field of biology education research has matured to the point that we can do more than review theory in the introduction of a paper without explicitly relying on the theory to inform research and interpretation. These papers are examples of using change theory throughout a paper: Marbach-Ad and Hunt Rietschel, 2016; Matz and Jardeleza, 2016; Goodwin *et al.*, 2018; Reinholz *et al.*, 2019; Hill, 2020; Archie *et al.*, 2022; Viskupic *et al.*, 2022.

Relate Findings Back to Grounding Change Theories

The use of change theory in STEM higher education is relatively new and we have much to learn about how to achieve systemic and individual change in these contexts. As our research makes new discoveries, we can represent this new knowledge by modifying the change theories that guide our work. Many change theories hail from different fields and they require adaptation to the contexts we aim to reform. The next frontier for change research in biology education is to not only use formal change theory but to tailor and refine

theory for specific contexts of STEM higher education. Researchers can do this by discussing the ways in which their findings align with and differ from the predictions of a change theory. This may result in researchers proposing ways to tailor or refine a theory for STEM higher education, or confirming that a theory has strong explanatory power in STEM higher education. The discussion section of a paper is a common place for including these ideas. Researchers can also serve the discipline by sharing how they synthesized multiple change theories to inform their work, perhaps by describing this in the introduction and then discussing it in light of the findings at the end of a paper (e.g., Kezar and Holcombe, 2021). In these ways, researchers share findings from their unique change context and also contribute to our more generalizable knowledge about achieving change across more than one context. What we learn in our own work will be more likely to be taken up if readers can understand how it relates to findings from other studies, and change theory can be a bridge connecting findings from multiple studies. These papers are examples of how researchers related their discoveries to change theory: Henderson and Dancy, 2008; Andrews and Lemons, 2015; Froyd *et al.*, 2017; Reinholz and Apkarian, 2018; Hill, 2020; Viskupic *et al.*, 2022.

SUMMARY AND CONCLUSIONS

This essay is designed to provide terminology, practical examples, and guidance for change agents and change researchers within biology education and STEM education more broadly. The problem of changing higher education teaching and learning has proven to be daunting enough that we need to take advantage of every available tool to aid our efforts, including building and revisiting theories of change specific to our change initiatives and using formal change theory to inform our interventions and research¹. Fortunately, the use and understanding of change theory has blossomed over the past decades, to the point where researchers now have a large body of prior work to build on, and accessible summaries of this work. This provides an opportunity for researchers to develop a greater understanding of change and to use it in theory and practice.

As a field, biology education has a unique advantage in guiding documents such as Vision and Change (AAAS, 2011). This document provides a level of coherence on the types of long-term outcomes that biology educators can hope to achieve for their students. This provides more guidance than a field such as mathematics, which has less consensus around learning targets for students. Vision and Change, and a growing body of related research and resources (e.g., Brownell *et al.*, 2014; Brancaccio-Taras *et al.*, 2016; Couch *et al.*, 2019; Branchaw *et al.*, 2020; Clemmons *et al.*, 2020) may offer the “what” we aim to change but don’t describe “how” to get there. That is where formal change theory comes into play. Change theory is an essential tool for helping us capitalize on existing knowledge about how to achieve change in undergraduate biology and for advancing the frontiers of knowledge about change in STEM higher education.

¹McLaughlin, M. W., & Mitra, D. (2001) may be a useful resource for readers as it discusses theory-based change in K12 education.

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