Introduction
Since innovation refers to a component, device, system, process, or practice that is different from existing components, devices, systems, processes, or practices, productive examination of innovation in any field requires some effort to establish what is considered existing set of components, devices, systems, processes, or practices. Therefore, a white paper on propagation and realization of educational innovations must establish some foundation, baseline, starting point, and/or context as a background for conversations about innovation. Further, the term innovation, as frequently used today, suggests it addresses some need; therefore, it seems reasonable to ask about needs for educational innovations to address. Finally, innovators in engineering and science draw on vast scientific, engineering, legal, economic, marketing, and many other knowledge bases to guide implementation of the processes through which they generate innovations. Innovators creating educational innovations in undergraduate STEM education should be able to draw up similar knowledge bases. The following assertions about undergraduate science, technology, engineering, and mathematics (STEM) education are offered to understand current practice with respect to these three points before directly addressing the four questions about innovation in undergraduate STEM education that were posed in the commission of the white paper. These assertions are offered in response to questions that are related to innovation.

1. What are pervasive practices in undergraduate STEM education? As a baseline, teaching practices described below will be referred to as pervasive practices in undergraduate STEM education. If these are a baseline, then educational innovations could be described as practices that are different from these. Sometimes, these pervasive practices are summarized characterized by the phrase “teaching as you have been taught”. Of course, standard cautions apply because many faculty members teach many courses that deviate in one or more ways from these practices, so pervasive is not meant to imply universal. Also, pervasive is not meant to imply ineffective; millions of students have graduated from institutions in which these pervasive practices are employed, and the vast majority of these students have made contributions to employers and society. Furthermore, there are many practices that might be added to the list of pervasive practices, including those related to undergraduate advising and faculty development.

   a. Classroom practice: The faculty member lectures about one or more topics relevant to the course to a room full of students for the vast majority of the classroom period. The remainder of the classroom period is used for course and classroom management, e.g., announcements about upcoming due dates and exams, returning exams, announcing procedures by which exams may be picked up, and describing course policies and procedures.

   b. Course design and implementation practice: The faculty member, based on her/his domain expertise, decides on the set of topics to be covered in the course, arranges the topics in a logical order often using prerequisite knowledge as a principle for
organization. Often, choice of these topics is influenced by expectations from downstream courses that list the course under consideration as a prerequisite course. Examinations are given at the end of the course and at a small number of intermediate times.

c. **Curricular design and implementation practice:** Each college or university has a set of requirements that every curriculum certified by the institution must satisfy. Beyond these constraints, a department selects a mixture of required and elective courses based on the past curricula and the motives and expertise of the faculty members. In designing these curricula, content coverage, to the extent judged important by the departmental faculty has been a primary criterion. Program outcomes, required for accreditation by ABET for engineering programs, but less rigorously defined in other STEM fields, are incorporated as a necessary add-on.

**(2) Is there a need?** Based solely on analyses of national reports (National Academy of Engineering, 2004, 2005; National Research Council, 1999, 2003a, 2003b, 2003c, 2005; National Science Board, 1986; National Science Foundation, 1992, 1996) on undergraduate STEM education, there appears to be universal agreement that if systemic changes are not made to the pervasive practices mentioned previously, then expectations for improved student learning, increased enrollment in STEM disciplines, and student graduation rates in STEM disciplines will not be achieved. While the degree to which STEM faculty members across the United States agree with this assertion is not well understood, there is some reason to think that a majority would not support this assertion. Research on the degree of the support for the assertion as well as reasons offered for either supporting or contending with the assertion might shed additional light processes associated with adaptation of innovations in undergraduate STEM education.

**Is there a research base to support innovation in undergraduate STEM education?** There is a substantial body of literature in the in the interdisciplinary field of STEM education at the undergraduate level on classroom, course, and curricular design and implication practices that offer alternatives to the aforementioned pervasive practices. The Board of Science Education (BOSE) of the National Academy of Science (NAS) is conducting a study on disciplinary-based educational research (DBER) and has commissioned a series of white papers on educational research in several STEM disciplines. Publication and analyses of these white papers might provide a clearer picture of the research base that exists to support innovation in undergraduate STEM education. In addition to the research in general supporting innovation in undergraduate STEM education, there is a literature base on practices that offer alternatives to the pervasive practices presented above. Depending on how these alternative practices are identified and classified, the list could be very long or might fit on a single page. Many of these practices could be labeled as innovations, but some people might question that label for some practices since they have been used, in some cases, for many years. It is not the intent of this white paper to present yet another summary or synthesis of the research base that already exists to support innovation in undergraduate STEM education.

As commissioned, this white paper intends to address both realization and propagation of educational innovations. As will be suggested below, there are indications that there is not a serious deficiency in the number of innovations that have been generated in the past twenty years. However, as the consensus of national reports suggests, these innovations have not systemically influenced undergraduate education in any one of the STEM disciplines. This cursory and preliminary analysis suggests that increasing likelihood of systemic change in undergraduate education in one or more of the STEM disciplines depends more on understanding how innovations are propagated and then acting on this
understanding than on greater understanding of processes for realization of educational innovations. For this reason, questions about propagation of educational innovations will be addressed first.

**Propagation of Education Innovations in Undergraduate STEM Education**

For engineers and scientists familiar with applications of diffusion in their work, the phrase “diffusion of educational innovations” may be confusing. Diffusion in engineering and scientific applications refers to transfer of mass due to a concentration gradient, i.e., mass of a particular species moves from a region of higher concentration to a region of lower concentration. Further, mass is a conserved quantity so when mass is transferred from region A to region B, region A ends up with less mass and region B with more. Educational innovations do not behave according to either the principle of conservation or the principle of concentration gradients. For example, if someone who has not adopted the innovation decides to adopt the innovation, one or more current users of the innovation do not have to forfeit application of the innovation. Also, propagation of educational innovations depends more critically on decisions by faculty members who, at some point in time, are not using the innovation about whether they will investigate the nature of the innovation and whether they will begin using the innovation, of course modified by the beliefs, preferences, and experiences of the adapting faculty members. In this way, educational innovations are not adopted, they are adapted. As a result, educational innovations may not behave in ways that characterize diffusion of mass. Since the phrase “diffusion of educational innovations” may summon, consciously or unconsciously, mental models about diffusion of mass, the phrase will be avoided in this paper. In its place, the phrase “propagation of educational innovations” will be used. It is unlikely that use of this phrase in this paper will influence the general conversation about movement of education innovations.

For this white paper, two questions have been posed about propagation of educational innovations:

1. What are possible human, organizational, and resource factors affecting propagation of educational innovations?
2. What are possible metrics by which to measure propagation of educational innovations?

Each question will be explored in the following sections.

**Factors Influencing Propagation of Educational Innovations**

The starting point for addressing the question about factors influencing propagation of education innovations would be the work by Rogers (2003). In the seminal synthesis of the research on propagation of innovations, factors that Rogers identified as influencing the extent and rapidity with which innovations spread might be grouped into three sets:

- Perceived attributes of the innovation, i.e., how do potential innovation adapters perceive the innovation?
- Characterization of the environment or context in which potential adapters of innovations learn about innovations and make decisions with respect to innovations, i.e., what is known about how potential adapters are influenced by their environment?
- Extent of change agents’ promotion efforts, i.e., what are the approaches that change agents use to promote innovations and how much energy and resources are invested in the promotion efforts?

Each of the three factors will be explored in the following paragraphs.

There are many attributes of an innovation that potential adapters might consider as they learn about it and make decisions regarding future actions. Here, continuing to draw from the work of Rogers (2003) and including the synthesis by Wejnert (2002), three are emphasized.
Compatibility “refers to consistency of the innovation with values, experiences and needs of potential adapters” (Borrego, Froyd, & Hall, 2010).

Complexity “refers to the perceived (or actual) difficulty of adopting the innovation. Some innovations ... can be adopted by a single faculty member, while others require coordination across departments and other academic units. Rogers explains that the higher the perceived complexity of an innovation, the lower its rate of adoption” (Borrego et al., 2010). Complexity also includes anticipated or perceived student resistance to adoption of a new approach to teaching (Cooper, MacGregor, Smith, & Robinson, 2000; Felder & Brent, 1996; Keeney-Kennicutt, Gunersel, & Simpson, 2008).

Under perceived attributes, the phrase “perceived benefits” of the innovation refers to potential adapters’ perceptions of the advantages of adapting the innovation. For faculty members, adapting an educational innovation influence one or more of the following areas:

- Perceptions of the responsibility of teaching, e.g., adaptation of an educational innovation may make teaching more enjoyable or more fun (Foundation Coalition, 2002; National Institute for Science Education, 1997).
- Perceptions of changes in the time required for teaching, e.g., adaptation of an educational innovation may save faculty members time or may require more time (Henderson & Dancy, 2007). Research by Sunal and others showed that faculty in their survey, which asked respondents to identify barriers to change, ranked “resources, time, and turf conflicts” as “very important” 60% of the time (Sunal et al., 2001).
- Improvements in student’s perception of the classroom and/or course
- Improvements in student learning. The literature for many educational innovations includes studies showing improvements in student learning (for example, Froyd, 2008; Hoffman, Hosokawa, Blake, Headrick, & Johnson, 2006; Lewis & Lewis, 2005; Prince, 2004; Springer, Stanne, & Donovan, 1999; Tien, Roth, & Kampmeier, 2001). However, faculty members offer many reasons to discount the research showing connections between changes in educational practice and improved learning. These include: “The study was done in field X and I teach field Y.”, “The study was done at an institution that is different than the one I teach at.”, “The study did not sufficient control for other variables that may explain findings.”, and “I am skeptical about findings from educational research.” (Borrego et al., 2010).

Interactions between potential adapters and the context and environment are very complex. Again, the work by Rogers provides guidance in selecting more specific opportunities for focus:

- Type of innovation-decision: “The type of adoption decision can be optional, collective or authority. Many engineering education innovation adoption decisions are optional among faculty members, particularly those that take place in one course in one department. Adoption of more complex innovations, in this case those requiring coordination across academic units, may need to be a combination of collective and authority decisions. Authority decisions can be made more rapidly than collective decisions, but may be undermined in actual implementation, while collective decisions may lead to embodiments of an innovation that may be sustained” (Borrego et al., 2010)

- Local Factors: Dancy and Henderson (Henderson & Dancy, 2007), through interviews with physics faculty, some of whom had beliefs that were aligned with theories emerging from physics education research, but had not adopted research-supported pedagogies, found several structural barriers to adoption of research-supported pedagogies. These included anticipated resistance from students, the one-size-fits-all schedule of courses that meet three fixed-length
times a week for a semester, amount of material that is expected to be covered in a single course, department norms that support traditional approaches, and lack of time (see above). Student resistance to pedagogies that expect more active participation in class has been reported elsewhere (Cooper et al., 2000; Felder & Brent, 1996). Cooper et al. (2000) offer the following strategies to address anticipated student resistance: clarify changing expectations before and during implementation of new strategies, create meaningful activities that encourage students to process information in different ways and yet that are at an appropriate level of difficulty and complexity, and clarify expectations for each learning activity. Felder and Brent (1996) list several student complaints about innovative pedagogies and offer ways in which faculty members might address each area of resistance. Felder and Brent (1999b) cite content coverage as a frequently asked question in their workshops on effective teaching and offered one way to address this issue: put significant material that you would cover in lecture into class handouts and announce that you will not go over in detail material in the handouts, but that students are responsible for material in the handouts (Felder & Brent, 1999b). This is one way to cover material and create class time for alternative activities that may lead to deeper learning. In a series on frequently asked questions, Felder and Brent address several questions that faculty members raise about implementing alternative pedagogies: where is the evidence that they work (Felder & Brent, 1999a), content coverage (Felder & Brent, 1999b), large classes (Felder & Brent, 1999b), group work and distance learning (Felder & Brent, 2001a), student hostility to teaching methods that require them to take more responsibility for their own learning (Felder & Brent, 2001b), low student motivation (Felder & Brent, 2001b), how to design fair tests (Felder & Brent, 2002), evaluating teaching (Felder & Brent, 2003), and persuading other faculty to use nontraditional methods (Felder & Brent, 2003). Finally, department norms for instruction (Henderson & Dancy, 2007) are linked to another possible source of resistance, lack of alignment with organizational culture (see below).

- Communication channels: “Communication channels can be mass media or interpersonal. In engineering education, mass media includes journal articles, conference publications, and professional society publications such as ASEE Prism. These are contrasted with interpersonal channels, such as having an informal conversation with someone describing his or her positive experience with an engineering education innovation. Rogers explains that mass media channels are more important at the awareness stage, while interpersonal channels are critical at the evaluation stage” (Borrego et al., 2010). In the study of engineering department head perceptions of adoption of seven innovations in engineering education, department heads were asked about how they heard about each of the seven innovations. “The most common method was word of mouth (28%), followed closely by presentations on campus or at conferences (not including technical professional societies) (23%). These relatively high percentages are in stark contrast to very low rates of reading about innovations (at least initially) or hearing about them through technical professional societies. These results indicate that engineering department chairs are not generally engaging with engineering education literature, or not recalling it. However, given the relatively high awareness rates, coupled with Rogers’ predictions regarding communication channels at various stages of the adoption process, interpersonal interactions are most likely to encourage adoption in the future” (Borrego et al., 2010).

- Culture: The culture of an institution influences success or failure of change initiatives (Kezar & Eckel, 2002). Analysis of two different change initiatives within a single institution showed how the initiative that led to a more sustainable curriculum aligned better with the culture of the institution (Merton, Froyd, Clark, & Richardson, 2009). “As these examples illustrate, change agents should ‘realize that the culture of the institution (and institutional type) affects change’ and seek a better understanding of the culture of the institution” (Froyd, Henderson et al.,
Schein (1992) portrays culture in three levels: artifacts and actions that could be observed; values and behavioral norms that are frequently mentioned by organizational leaders; and shared, underlying assumptions that are rarely mentioned, but direct decisions because they were influential in the early success of the organization. Bergquist and Pawlak (2008) assert that cultures of institutions fit into one of six types: collegial, managerial, developmental, advocacy, virtual, and tangible. These typologies may be useful for change agents (see below) in understanding the culture for a change initiative and how the initiative can be formed to align with the culture.

- **Interpersonal Networks**: “When two individuals share common meanings, beliefs, and mutual understandings, communication between them is more likely to be effective” (Rogers, 2003, p. 306). “This explains, for example, why engineering educators, like those in other disciplines, tend to discount the results of research studies which did not include engineering students; they desire information on settings similar to their own (Lattuca & Stark, 1995; Wankat, Felder, Smith, & Oreovicz, 2002)” (Borrego et al., 2010).

The final set of factors describes the nature of efforts by one or more change agents to promote one or more innovations. One question that could be raised in connection with this set of factors is: Who are the change agents? Across the communities connected with undergraduate STEM education, there are multiple answers. In order to reduce, the breadth and complexity of the communities to be considered, examination of this question will be restricted to communities related to one specific field with which the author is more familiar than other possibilities: undergraduate engineering education. Even within this restricted set of communities, addressing the question is complex. One set of change agents would be the individual investigators and small groups of investigators that NSF has empowered through funding their submitted proposals for research and innovation in engineering education. Another set of change agents could be companies who employ engineering graduates and who seek to improve the competencies and capabilities that engineering graduates bring. Another set of change agents would be government organizations who desire improvement in engineering education, for example, NSF. Still another set of change agents would be non-governmental organizations seeking the same goal. A primary example of this category of change agents would be ABET. A very visible example of change that has occurred in engineering education over the past twenty years would be replacement of process-based criteria that ABET used to accredit engineering programs in 1990 to the outcomes-based criteria that are used for accreditation in 2010. Different categories of change agents will bring different capabilities, resources, and constraints to challenges of catalyzing change in engineering education. It appears difficult to offer further description of nature of the efforts by change agents without clarifying which category of change agents are being considered.

Another set of issues that change agents must address is articulation of ends or goals for their change initiatives. As a starting point for exploration of the nature of these goals, consider the criteria that NSF has used in evaluation proposals related to innovations in undergraduate STEM education. These programs have included the Course, Curriculum, and Laboratory Improvement (CCLI) program, the Innovations in Engineering Education, Curriculum, and Infrastructure (IEECI) program, and the TUES program. In evaluating proposals for these and other programs, one or more of the criteria relate to what has traditionally been referred to as the dissemination plan. In a dissemination plan, based on the definition of dissemination, the end envisioned is greater awareness across a broad, vaguely defined community of the funded educational innovation. Approaches used in many dissemination plans have included conference papers, archival journal papers, and web sites. As mentioned earlier, Rogers (2003) has shown that these mass media approaches tend to be effective in increasing awareness, but different, more interpersonal approaches, are required to facilitate transitions to stages beyond
awareness. Concerns have been raised about effectiveness of dissemination plans, but since the end envisioned by dissemination plans is awareness, concerns may be unfounded. In a survey of engineering department heads regarding seven innovations in engineering education, awareness among the respondents was at least 60% and reached as high as 96% (Borrego et al., 2010). If awareness is the envisioned end, then the end could be said to have been realized, at least in the case of the seven innovations studies in the project. As was stated above, different categories of change agents will face different issues to determining goals for their change initiatives.

However, awareness may be just the first step in Rogers (Rogers, 2003) sequence of adoption stages. If, for funded proposals, change agents are expected to influence decisions of potential adapters with respect to stages beyond adoption (Froyd, 2001), then re-examination of ends of dissemination plans is warranted. Clarity of the expected ends or goals is critical, because plans are made to achieve ends. If envisioned ends are inaccurate or vague, then plans made to achieve these ends may be without value. If the envision ends include greater adaptation of education innovations across a community of STEM educators, then influencing decisions made by potential adapters in stages of adoption beyond awareness becomes an important consideration for change agents. In this case, if change is the goal, Froyd and others have highlighted the importance of goals when formulating dissemination or change plans (Froyd, Beach, Henderson, & Finkelstein, 2008; Froyd, Henderson et al., 2008; Froyd, Layne, & Watson, 2006). Another consideration is the nature of the innovation to be adapted. For example, is it expected that, within a community of STEM educators, faculty members will be adapting a specific educational innovation, for example, peer-led team learning (PLTL) (Tien et al., 2001) in general chemistry? Or is the goal, for example, movement of faculty members teaching chemistry away from lecture and toward anyone of a set of innovations? Is adaptation of a particular innovation critical, or is adaptation of an innovation or combination of innovations from a large set satisfactory? The distinction is critical. Henderson, Finkelstein, and Beach, in their study of change initiatives in higher education, use the answer to these two questions, or questions similar to these questions, to partition the change strategies they found into two subsets: prescribed outcomes in which “the change agent knows upon initiating a change process what kind of behavior or mental states in individuals or groups are expected and sought, driven by the assumption that the change agent has the key knowledge needed to define the outcomes” and emergent outcomes in which “the end state in terms of behaviors or mental states are determined as part of change process, with the assumption that those involved in the change have important information needed to define the outcomes” (Henderson, Finkelstein, & Beach, 2010). Without clarity regarding expectations for ends of efforts by change agents, no progress can be made in recommending strategies that should be considered or in evaluating efficacy of the efforts by change agents.

Another set of questions that change agents must address in formulating their plans and allocating their resources related to decisions is who should be influenced. Without careful consideration and articulation of a chosen audience for influence, change agents risk spreading their efforts over the very large engineering education enterprise with no perceptible results. Given the diversity of change agents and their aspirations, at this point, the most informative statement that the author can make is that change agents must make thoughtful decisions about sizes and positions of individuals and organizations that they intend to influence.

Another set of decisions for change agents to achieve their goals involves answering questions like, “What will change in order to achieve the goals?” One example of a choice that a change agent might make for this set of decisions is whether the intent will be to change the curriculum of a course or set of courses or to change faculty members who teach the course. So, for example, an initiative to improve
first-year retention of engineering students might select to alter either the first-year engineering course or courses. However, if course changes are desired, it is necessary to ask, “What is going to be changed in the first-year courses?” Are changes in the catalog description sufficient? Are changes in the course syllabus or syllabi sufficient? Are changes in the way the course is taught, e.g., active/cooperative learning or problem-based learning, sufficient? Felder et al. list seven well-supported improvements to teaching practice: (1) formulate and publish clear instructional objectives, (2) establish relevance of course material and teach inductively, (3) balance concrete and abstract information in every course, (4) promote active learning in the classroom, (5) use cooperative learning, (6) give challenging but fair tests, and (7) convey a sense of concern about students’ learning (Felder, Woods, Stice, & Rugarcia, 2000). Suppose one instructor who teaches the course makes changes to the course content and the way the course is taught. Next year, another instructor who teaches the course decides that the content and pedagogical changes are not justified and teaches the course as it was taught before the changes. Is the course changed? Curricula and courses are outward manifestations of how faculty members think about learning, assessment, and teaching. If conceptions of faculty members regarding learning, assessment, and teaching are not changed, it seems reasonable to ask how much paper changes to curricula and courses, e.g., catalog descriptions and ABET course syllabi, will achieve the espoused goals. These are questions that were addressed by Woodbury and Gess-Newsome in their study of change in college science courses (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003; Woodbury & Gess-Newsome, 2002). They concluded that curricula and course changes often resulted in what they labeled “change without difference” (Woodbury & Gess-Newsome, 2002). Instead, they called for “focus on encouraging and supporting change in teachers' work as the center of reform efforts” (Woodbury & Gess-Newsome, 2002). This reinforces the importance of “staff development” as one of five key factors identified by Eckel and Kezar (Eckel & Kezar, 2003) that support successful transformations. So, in many cases, change initiatives that were initially conceptualized as curriculum development become faculty development initiatives (Clark, Froyd, Merton, & Richardson, 2004).

Possible Metrics for Measuring Propagation of Educational Innovations

Determining the extent to which an educational innovation has propagated across a particular STEM discipline education community appears, at first glance, straightforward, although perhaps not easy. A survey could ask faculty members in the community about whether they are using a particular innovation. However, unlike artifacts (e.g., TVs, cell phones, toaster ovens...), referring to educational practices assumes a common vocabulary about these practices across the community. It is likely that many engineering faculty members, for example, have not heard about process oriented, guided inquiry learning (POGIL), so if they are asked if they are using POGIL-based practices, the likely response is no, even if their instructional practices conform to many of the guidelines advocated by this educational practice. Further, getting response rates to national surveys of STEM discipline education communities up to levels at which survey results can be truly meaningful indicators of the extent to which an innovation has propagated can be problematic (Borrego et al., 2010). Beyond these issues is the question of whether the community values knowledge of the extent to which a particular innovation has propagated. Of more interest may be the extent to which a set of educational innovations, classified into the set because they met some similarity criteria, has influenced practice across the community. If this is the question, the determination of the set becomes an issue to be resolved. If and when knowledge of the propagation of a set of innovations is determined, then questions about how and why the set of innovations propagated (or failed to do so), and the conversation returns to the question about the factors that influence propagation of education innovations in undergraduate STEM education.
Realization of educational innovations in undergraduate STEM education is defined, for the purpose of this white paper, to be the generation of educational practices that are different from the set of pervasive practices described in the introduction. In engineering education, as mentioned in the introduction, there are at least two conferences each year, the ASEE Annual Conference & Exposition and the Frontiers in Education (FIE) Conference, at which attendees present innovative practices. Other STEM disciplines are likely to be able to report similar observations. The number of papers presented at these conferences and the numbers of attendees suggest that there is no lack of innovative practices being generated. Another report states that “[f]aculty members routinely change their courses from semester to semester, experimenting with both minor changes and major innovations, according to a national survey released Saturday by the Bringing Theory to Practice program. But while professors see curricular innovation as part of their jobs, they remain uncertain about whether pedagogical efforts are appropriately rewarded, the study found” (Inside Higher Ed, 2010). So it appears that there is constant generation of innovation in undergraduate STEM education. Given this situation, why would questions be raised about realization of innovations in undergraduate STEM education?

At least four issues might be raised about the observation of ubiquity of generation of educational innovations in the previous paragraph:

- First, when one faculty member does something different in her/his course than the last time she/he taught the same course, does qualify as an educational innovation? Is there a lower bound on the number of faculty members using a particular practice to qualify as an education innovation?
- Second, when one faculty member does something different, but it is very similar to what another faculty member has done, does that qualify as an educational innovation? If a faculty member in physics decides to use the Peer Instruction approach described by Eric Mazur (Mazur, 1997) that she/he has never used before, does this qualify as an educational innovation? Suppose the disciplinary boundary is crossed, i.e., suppose a chemist was the first to use the Peer Instruction approach in any undergraduate chemistry course, does this qualify as an educational innovation? Questions have been raised about the degree to which ideas presented in conference papers and proposals to the NSF program in Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES) might be categorized as innovations. One reason might be because of the degree to which they resemble already published practices, while another reason might be because of the degree to which the authors have applied prior work in making their design decisions that resulted in the presented practice. The question might be posed another way: When a faculty member does something different for her/his course, but the practice is similar to what another faculty member already has done, is this realization of an innovation or propagation of an innovation?
- Third, does a practice that is different from the pervasive practices described above have to be based on a body of research to qualify as an educational innovation? Another reason that questions might be raised about whether a different approach that a faculty member tries in her/his course qualifies as an innovation is to what extent the approach draws upon the existing body of knowledge to inform decisions that led to the approach. Is the faculty member just making things up as she/he teaches the course. The ASEE report (Jamieson & Lohmann, 2009) co-shepherded by Leah Jamieson and Jack Lohmann refers to tendencies by engineering faculty members to develop alternative practices based almost completely based on intuition and trial-and-error, as opposed to also drawing upon published scholarship. Thus, for engineering faculty members, they fail to apply engineering processes, such as engineering design processes, to
creation, design, implementation, and operation of their engineering courses. Further, there are tendencies to classify as innovations some practices simply because they represent early adoption in a particular discipline, while the practice may have been underway for some length of time and by a number of practitioners in another discipline. The author is unaware of similar reports in other STEM disciplines.

- Fourth, does a practice that is different from the pervasive practices described above have to be supported by a body of evidence supporting its efficacy in achieving stated goals to be categorized as an innovation?

At this point, it does not appear that there is not a need to improve the number of educational innovations in undergraduate STEM education, nor is there a need to improve the processes associated with realization of education innovations. So, further exploration of the factors associated with realization of educational innovations and metrics associated with realization will be postponed until there is sufficient understanding of the issues associated with realization.

**Conclusions**

Many studies, several of which could be considered seminal, offer factors that influence how educational innovations propagate across communities that support undergraduate STEM education (Borrego et al., 2010; Eckel & Kezar, 2003; Froyd et al., 2006; Henderson et al., 2010; Kezar & Eckel, 2002; Rogers, 2003; Schein, 1992; Senge et al., 1999; Wejnert, 2002; Woodbury & Gess-Newsome, 2002). People and organizations who accept responsibility for influencing practices across the spectrum of undergraduate STEM education activities have been referred to as change agents. Their efforts play a pivotal role in propagation of educational innovations.

One of the challenges that these change agents face is applying the knowledge base on propagation of educational innovations to create actions that are likely to catalyze and maintain sustained, systemic improvement (Froyd & Watson, 2000) in undergraduate STEM education. Given the complexity of factors influencing propagation and the time scales over which effects of sustained propagation will become visible, concerns might be raised about, not importance or criticality, but visibility and ability to observe consequences of individual change agents working for one, two, or three years. As an example of visible, systemic change in a set of STEM disciplines, namely engineering, the shift in accreditation criteria to emphasize articulation, assessment, and application of educational objectives and outcomes has influenced the practice of undergraduate engineering education at a national scale. Questions may be raised about the degree to which the practice of individual engineering faculty members has changed as a result of the shift in accreditation criteria. However, it is unlikely that questions could be raised about the scope and systemic nature of the change. Incorporating educational outcomes as a core element of accreditation has taken twenty years and involvement of at least hundreds of individuals and organizations. If shifts of similar or greater scope are expected in undergraduate STEM education across all its disciplines, similar time periods may be expected if sufficient individuals and organizations are willing to commit. Resources on a scale that matches the immensity of the challenge may accelerate a national movement, but that has not been demonstrated. Given the size of the resources that the United States has been willing to commit to the realization and propagation of educational innovations over the last 20 years and uncertainty about the degree to which a change will be accelerated, it is unlikely sufficient investment will be made.

**References**


