White Paper on Promising Practices in Undergraduate STEM Education

Jeffrey E. Froyd

Texas A&M University

Introduction

Numerous calls for improvement in undergraduate science, technology, engineering, and mathematics (STEM) education have been made (National Academy of Engineering, 2004, 2005; National Research Council, 1999, 2003a, 2003b) and the Board of Science Education of the National Academies has established a committee to recommend a list of promising practices in undergraduate STEM education. To support the committee in its work, this white paper offers a set of promising practices using two sets of standards: implementation and student performance, against which each promising practice will be evaluated. Each promising practice offers an alternative for one or more of the decisions that faculty members or curriculum program committees make as they construct courses or curricula.

Decision-making Framework for Course/Curriculum Development

To develop the list of promising practices, a first step was to establish a list of current, widespread approaches that will be referred to as traditional practices. This set of traditional practices is set within a framework of decisions that both faculty members and curriculum program committees make as they design either a course, in the case of a faculty member, or a curriculum, in the case of a committee. The decision-making framework is imperfect. First, it is ad hoc; it was constructed for the purposes of the paper and does not draw upon prior frameworks. Second, it is incomplete; it does not include many decisions that need to be considered, such as what to do on the first day of a course (Perlman & McCann, 2000; Wilson & Wilson, 2007), and how faculty members might help students improve their abilities to learn (Pintrich, 2004; Weinstein, 1994). Third, the decisions interact; that is, some of the decisions have implications for other decisions. Nevertheless, it includes many decisions that are made by faculty members or committees in the course/curriculum design process.

The framework highlights several traditional practices that will provide counterpoints for the promising practices that are presented later. For this paper, the perspective has been taken that promising practices should provide alternatives to traditional choices for one or more decisions that faculty members and/or curriculum program committees make as they design and/or implement courses or curricula. Finally, although the framework sets forth decisions that are made by individual faculty members or curriculum program committees, the rest of the paper will present the decision-making agent as an individual faculty member. This choice is made both for simplicity, so that constant reference is not made to both faculty members and committees, and for practicality, because most examples of the promising practices have been choices of individual faculty members. There are only rare examples of alternative approaches that have been tried at the entire curriculum design grain size. Table 1 shows the individual decisions in the framework and briefly describes the traditional practice associated with each decision.

Table 1. Overview of Course Design Decision Framework with Traditional Practices

Decision	**Description and Traditional Practice**
Expectations Decision	For this decision, a faculty member must decide how to formulate, articulate, and communicate her expectations for student learning. Traditionally, the approach is to describe the content to be presented in the class and a widely used format for content description is a list of topics.
Student Organization Decision	During the course, students will engage in many different learning activities, both in and out of the classroom. For these activities, a faculty member must decide student organization for these activities. Traditionally, faculty members elect for students to participate in learning activities as individuals.
Content Organization Decision	Given the explosion in STEM content, faculty members face important decisions when deciding what content to include and how selected content will be organized. The traditional approach, reflected in both textbooks and course syllabi, is to select a set of topics using a set of priority criteria and organize the content by prerequisite chain. That is, faculty members order content in a logical sequence by answering the questions such as, “If topic A were included, what topics need to be presented prior to presentation of topic A.” As a result, when students ask why they are learning topic X, a faculty member may justify its inclusion by saying that it is needed to support work with future topics.
Feedback Decision	Another decision that faculty make in constructing a course is to decide how and when they will provide feedback to their students about the quality of their learning and/or progress in the course. Often, faculty members decide, sometimes tacitly, to provide feedback to their students by returned graded exams, quizzes, reports, and/or homework.
Gathering Evidence for Grading Decision	In almost every course, students receive a grade, which serves multiple purposes. An important decision that faculty members make is selecting the evidence that they will use in assigning grades. Traditionally, faculty members have used combinations of examinations, writing assignments (e.g., lab reports, project reports), oral presentations, quizzes, and homework.
In-class Learning Activities Decision	For semester-long courses that meet three times per week, there are approximately 40 class meetings. For each of these meetings, faculty members must select learning activities in which the class will be engaged. Although there is a wide spectrum of possible activities, the most frequently selected in-classroom learning activity is the lecture.
Out-of-	In designing a course, a faculty member must select out-of-classroom

classroom Learning Activities Decision	learning activities. For this decision, the traditional practice is to assign homework that is expected to be completed by individual students. Both this decision and the prior decision about in-class activities are related to the student organization decision.
Student-faculty Interactions Decision	Many studies (Astin, 1993; Braxton, Sullivan, & Johnson, 1997; Hurtado & Carter, 1997; Pascarella & Terenzini, 2005; Tinto, 1993) have shown the value of student-faculty interaction for student retention and success. As a result, another decision that faculty members make when constructing their courses is how they will address student-faculty interaction. Frequently, they wait for students to initiate interactions when they have questions or are encountering problems.

The following section will describe standards against which promising practices will be evaluated, and the succeeding section with set forth the eight promising practices.

Standards for Promising Practices

Since the goal of the paper is to propose a set of promising practices for lower division courses and programs of undergraduate STEM education, one issue to address is standards that will be used in evaluating a practice as promising. For the purpose of the paper, there are two sets of standards. The first set of standards describes the extent that faculty members change to adapt a practice. Do they need extensive, additional education? Do the classrooms have to be remodeled or refurbished? How much time and energy are required to apply the practice? Can they adapt the practice without extensive investment? Standards characterizing the extent of faculty change involved in applying an alternative teaching practice will be called implementation standards. The second set of standards describes evidence of student learning or performance (e.g., learning and/or retention) that are related to the implementation of a teaching practice. Are students retained at a higher rate? Do they perform better as measured by local criteria such as grades or nationally normed instruments? To what extent do performance and/or learning of students from one or more underrepresented groups improve when an alternative approach is implemented? If the study involved two groups of students, to what degree are the two groups comparable? The second set of standards will be called student performance standards. Each set of standards is described in more detail in the following subsections.

The two sets of standards are very different. One emphasizes ease of implementation, while the other focuses on positive influences on student learning and persistence. In this paper, the ideal promising practice would be highly rated against each set of standards. That is, it could be implemented with almost no change on the part of faculty members responsible for implementation, and it would have widely accepted evidence and support for improvements in student learning. Based on studies of characteristics of innovations that have diffused rapidly (Rogers, 2003), these ideal promising practices, if they existed, would be expected to be universally adopted within several years. However, none of the promising practices presented in this paper achieves the ideal. Nevertheless, examining both sets of standards allows each reader to assign individual weights to the two sets and evaluate the proximity of each promising practice to her/his ideal.

Implementation Standards

In their paper on teaching methods that work, Felder et al (2000) offered the following implementation standards:

- **Relevance:** Is the option appropriate for the STEM course? For example, innovations in laboratory courses would not be appropriate for non-laboratory courses.
- **Resource Constraints:** Is the option feasible within the constraints of space, time, and instructional resources (e.g., teaching assistants)? Some options may be appropriate for classrooms with significant computer resources, but not applicable for classrooms without these resources.
- **Comfort Level:** To what extent will an option require a faculty member to make adjustments to approaches to teaching? Effort expended to adapt an option for a course might be placed in this or the preceding category.

When evaluating a promising practice against the implementation standards the simple rubric shown in Table 2 will be used to assign evaluating ratings.

Table 2. Rubric for Evaluating Promising Practices against Implementation Standards

Evaluative Rating	Description
Strong/high	**Relevance** – Applicable to almost every STEM course **Resource Constraints** – Can be used in most the learning environments in most of the institutions across the country **Comfort** – Adaptation will not require extensive training, faculty can adapt practice in steps, almost all of the additional effort occurs during transition to new practice
Good	**Relevance** – Applicable to a majority of STEM courses **Resource Constraints** – Require additional resource investments **Comfort** – Adaptation would be enhanced by training that requires several days, faculty typically adapt practice all at once, little additional effort is required after transition
Fair/low	**Relevance** – Applicable to a minority of STEM courses **Resource Constraints** – Require significant additional resources **Comfort** – Adaptation will require significant adjustments in practice, will require practices that are not a part of typical

	faculty repertoire, will require ongoing additional effort, even after transition

Student Performance Standards

Student performance standards may be placed into one of two categories:

- **Comparison** Studies**:** Comparison of student performance and/or learning between a group of students using a promising approach and a group of students using the currently widely practiced approach, referred to as the traditional approach. Slavin (2008) summarizes some of the issues to be considered in evaluating the quality of comparison studies. None of the comparison studies that will be referenced in this paper used randomized, controlled trials. Some used matched comparison groups while other used comparison groups without careful matching.
- **Application Studies:** Many alternate approaches to teaching are described in the literature by authors who have applied a particular approach in courses they teach. Often, the authors describe the course in which they implemented the approach, how they implemented the approach, and some information (e.g., student reactions) about how well the implementation went. Although these application studies cannot be relied upon for a comparison of an alternate approach to a traditional approach, they provide information that other faculty members can use if they elect to try the alternate approach. To a certain extent, application studies may raise the comfort level of faculty members trying an alternate approach.

When evaluating a promising practice against the student performance standards the simple rubric shown in Table 3 will be used to assign evaluating ratings.

Table 3. Rubric for Evaluating Promising Practices against Student Performance Standards

Evaluative Rating	**Description**
Strong/high	Multiple high-quality comparison studies together with meta-analysis or other synthesis of several studies
Good	Fewer, but still several, high-quality comparison studies, or multiple comparison studies but with conflicting evidence from comparison studies or in the synthesis of these comparison studies
Fair/low	Two or fewer comparison studies, but multiple application studies

Promising Practices

In each of the following subsections, a promising practice will be describe and briefly evaluated against the standards presented in the previous section.

Promising Practice No. 1: Prepare a Set of Learning Outcomes

As far back as Mager (1962), who referred to learning outcomes as learning objectives, learning outcomes have been offered as a vehicle for formulating, articulating, and communicating expectations for performance in a course or curriculum. Learning outcomes portray the student (instead of the faculty member) as the performer, as in “the student will be expected to be able to do the following.” Also, learning outcomes use a verb that depicts an observable action or work product. Therefore, verbs such as understand, know, appreciate, value are excluded, because these depict mental states that cannot be observed. Both guidelines focus attention of the faculty member on how students will be expected to demonstrate the extent of their learning, and they clarify expectations of the teacher for students. The former provides a critical foundation for assessment and promotes efficiency in course development, while the latter contributes to student success. They provide a promising alternative to the use of topic lists to convey expectations for coverage and learning.

Faculty members, as domain experts, have knowledge required to formulate learning outcomes. While preparing a list of learning outcomes may be unfamiliar, they can prepare them with reasonable support from a center for learning and teaching. Learning outcomes can be used in every STEM course, and no additional resources are required for their use. Therefore, the practice has strong support when evaluated against implementation standards.

As far as student performance standards, the author is unaware of comparison studies in which one group of students participated in a course that employed learning outcomes, while another group of students participated in the same course without learning outcomes. On the other hand, faculty members can find numerous examples of peers who have prepared learning outcomes. Engineering programs that wish to be accredited must prepare a set of learning outcomes that are then vetted by appropriate stakeholders (ABET, 2008). Outcomes-based accreditation is becoming more widespread. As a result, although the use of learning outcomes is not presently supported by comparison studies, their use is supported by numerous application studies. Therefore, this promising practice is evaluated as good with respect to the student performance standards, although this rating conflicts with the criteria set out in the rubric in Table 3.

While many national reports have repeatedly called for a set of attributes for STEM graduates that these reports state are required by recent global, societal, and economic conditions, these reports have not taken steps to clarify these attributes in terms of learning outcomes. Frequently mentioned desirable attributes include critical thinking, lifelong learning, representation competence, interdisciplinary thinking, entrepreneurship, and systems thinking. However, these desirable attributes are often poorly characterized, and rarely supported with a set of associated learning outcomes. As a result, assessment practices, learning environments, and learning activities that might support these desirable attributes stall in development. Two prominent exceptions can be noted. First is the framework for self assessment (an important component of lifelong learning) that has been prepared by the faculty at Alverno College (Loacker, 2000). The faculty has worked collaboratively over many years to prepare, apply, and refine this framework. The second is the work of Susan Wolcott who has prepared a framework for assessment and teaching for critical thinking (Wolcott, 2006, first draft). If similar frameworks were available for many frequently mentioned desirable attributes, assessment and teaching to promote their development would be enhanced.

Promising Practice No. 2: Organize Students in Small Groups

A second promising practice is for faculty members to organize students in small groups for many of the learning activities both during class and/or outside of class. Pedagogical approaches in which faculty members organize students in small groups for learning are varied, and include collaborative learning (Bruffee, 1984), cooperative learning (Johnson, Johnson, & Smith, 1991), peer-led team learning (Gosser & Roth, 1998; Tien, Roth, & Kampmeier, 2001), team-based learning (Michaelson, Knight, & Fink, 2004) and peer instruction (Mazur, 1997). Also, other pedagogical approaches, such as problem-based learning (Boud & Feletti, 1997), project-based learning (Prince & Felder, 2006, 2007), service learning (Eyler & Giles, 1999), capstone design projects (Dutson, Todd, Magleby, & Sorensen, 1997), and inquiry-based learning (Lee, 2004) almost always involve organizing students in small groups.

In terms of the implementation standards (relevance, resource constraints, and comfort level), small group organization can be evaluated as strong. It has been applied in many contexts associated with STEM courses, and faculty members can use small groups within almost all existing instructional settings. However, faculty members will need to address several issues in using small groups, including:

- Forming small groups (Bacon, Stewart, & Anderson, 2001; Bacon, Stewart, & Silver, 1999; Brickell, Porter, Reynolds, & Cosgrove, 1994; Froyd, 2002b; Stewart, 2006)
- Getting groups off to good starts (Froyd, 2002c; Johnson & Johnson, 2000)
- Facilitating dysfunctional groups (Froyd, 2002a), and
- Helping students develop their collaborative skills (Algert & Froyd, 2002, 2003a, 2003b; Johnson & Johnson, 2000)

Although many resources (e.g., the resources in the preceding bullet list and campus centers for learning and teaching as well as J. L. Cooper, MacGregor, Smith, & Robinson, 2000; J. L. Cooper & Robinson, 2000; Johnson et al., 1991; Michaelson et al., 2004; Smith, 2000) are available to support faculty members in developing strategies for how they will make these decisions for their courses, using small groups requires faculty members to develop their skills and make changes to the way they teach. Therefore, using small groups rates slightly lower against the implementation standards than establishing learning outcomes, but it is still within reach of most faculty members. In summary, the practice of using small groups is rated as strong in terms of the implementation standards.

When evaluated against the student performance standards, using small groups rates higher than any other promising approach, except active learning (Promising Practice No. 6). Although small group organization has not been subjected to randomized trials at the undergraduate level, evidence for improvements in student performance when using small groups includes meta-analyses of multiple studies (Johnson, Johnson, & Smith, 1998; Springer, Stanne, & Donovan, 1999), reviews of multiple studies (Bowen, 2000; Prince, 2004), a longitudinal study (Felder, Felder, & Dietz, 1998), a study of student-reported learning gains across a coalition of institutions (Terenzini, Cabrera, Colbeck, Parente, & Bjorklund, 2001), evaluations over several years of implementation (Crouch & Mazur, 2001), and multiple quasi-experimental studies (Beichner et al., in press; Bonsangue, 1994; Born, Revelle, & Pinto, 2002; Tien et al., 2001; Wright et al., 1998). Hake (1998) evaluated approaches that he referred to as interactive-engagement against traditional methods of instruction in a total of 55 physics mechanics courses. On the average, the pre-to-post gain on the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) for courses using interactive-engagement methods was almost twice the gain in traditional mechanics courses. Buck and Wage (2005) showed almost identical results (although in fewer courses) in signals and systems courses using the Signal and System Concept Inventory (Wage, Buck, Wright, & Welch, 2005). Interactive-engagement approaches frequently, although not always, organize students in small groups.

Promising Practice No. 3: Organize Students in Learning Communities

Although most students take sets of courses each term, curricular decisions typically set courses that will be taken, but rarely attempt to design relationships, links, or connections among commonly taken sets of courses, e.g., calculus and calculus-based physics. In contrast, learning communities establish one or more structural (or pedagogical) mechanisms to help students relate and connect across multiple courses (Gabelnick, Macgregor, Matthews, & Smith, 1990; Taylor, Moore, MacGregor, & Lindblad, 2003). Learning communities address both student cognitive development by working on relating and connecting concepts, ideas, skills, and procedures as well as social development by supporting interpersonal relationships among students in academic contexts. The National Resource Center for Learning Communities describes learning communities as follows:

> "In higher education, curricular learning communities are classes that are linked or clustered during an academic term, often around an interdisciplinary theme, and enroll a common cohort of students. A variety of approaches are used to build these learning communities, with all intended to restructure the students' time, credit, and learning experiences to build community among students, between students and their teachers, and among faculty members and disciplines" ("Learning Communities National Resource Center: Frequently Asked Questions," n.d.)

Learning communities offer numerous alternatives for many course/curricular design decisions: student organization decisions, content organization decisions, in-class activities decisions, out-of-class activities decisions, and student-faculty connection decisions.

However, when evaluating promising practices, learning communities may not have yet reached the stage to be categorized as highly promising. When evaluated against implementation standards, they are highly relevant, because of the structured nature of STEM curricula, but they require resources at both teaching and administrative levels to establish structures that support learning communities. Furthermore, implementation of learning communities often requires that faculty members involved in linked courses need to make significant changes to their teaching practices to facilitate collaboration. Many faculty members may not be willing to work together in teaching their courses. As a result, learning communities are rated as fair in terms of implementation standards.

Also, considering student performance standards, the amount of evidence is less than the volume of evidence that supports many of the other promising practices. There have been several quasi-experimental studies for engineering curricula that have been summarized in Froyd and Ohland (2005). Further, the National Resource Center for Learning Communities prepared a report on assessment of learning communities (Taylor et al., 2003). However, the student performance standards rating for learning communities would be placed at the moderate level, at best.

Promising Practice No. 4: Scenario-based Content Organization

In contrast to the traditional practice of organizing content around a prerequisite chain of topics, the fourth promising practice offers a very different alternative: organizing content around one or more scenarios that are presented to students together with questions, challenges, problems, or projects posed in connection with these scenarios. Content is then drawn together to address these challenges. Scenario-based approaches to content organization have been implemented under a wide variety of labels. These labels include: problem-based learning, which originated in medical school curricula; project-based learning, inquiry-based learning, discovery learning, question-drive instruction, challenge-based learning, service learning, and model-eliciting activities (Diefes-Dux, Imbrie, Zawojewski, Capobianco, & Hjalmarson, 2004; Diefes-Dux & Moore, 2004; Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004; Lesh, Hoover, Hole, Kelly, & Post, 2000). Prince and Felder (2006, 2007) offer helpful overviews of the different approaches and supporting evidence. NSF supported an engineering research center, called VaNTH (Vanderbilt, Northwestern, University of Texas, and Harvard) (Cordray, Pion, Harris, & Norris, 2003) that redesigned bioengineering curricula around sets of challenges that were addressed in a structured approach called the STAR.Legacy cycle (Schwartz, Lin, Brophy, & Bransford, 1999) that had been pioneered prior to VaNTH. Mills and Treagust (2003) present several institutions across the world where their curricula are primarily problem/project-based. Chemistry in Context is a scenario-based approach to content organization for non-major chemistry courses that has been offered since its initiation in 1989 (American Chemical Society, 2009). The textbook that supports the Chemistry in Context approach is now in its sixth edition. Scenario-based approaches differ widely along several dimensions including the length of the activity during which students work on a challenge associated with the scenario, support offered to students or small groups of students as they engage the challenge, and guidelines offered to faculty members for the development of the scenarios and challenges.

Along the first dimension, activity length ranges from a few minutes, in which students address multiple questions in one class period [e.g., POGIL (POGIL, 2008), Physics by Inquiry (McDermott, 1996), and question-driven instruction (Beatty, Leonard, Gerace, & Dufresne, 2006)], to an entire year, in which students address a single challenge in great depth, often delivering a product to a customer [e.g., capstone design projects or service learning projects]. Along the second dimension, support ranges from no support [i.e., students are expected to discover the solution or concept on their own] to extensively structured support in terms of methodology and feedback. Mayer (2004) offers a stinging critique of approaches that offer no support (e.g., discovery learning, and some versions of problem-based learning) that have been offered under different names over a period of three decades. His critique is supported by Kirschner, Sweller, and Clark (2006) who show that minimal support approaches "ignore both the structures that constitute human cognitive architecture and evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process" (Kirschner et al., 2006). However, Hmelo-Silver et al (2007) have responded that inquiry learning and problem-based learning approaches "provide extensive scaffolding and guidance to facilitate student learning." These differences could be reconciled if some problem-based or inquiry-based implementations have offered little or no guidance (Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007) while other implementations have offered carefully constructed guidance and support. Differences in support offered to students as they address the challenges may account for some of the variability observed in comparison studies of scenario-based approaches. The third dimension is guidance for faculty members as they develop questions, challenges, or problems. Some references on these approaches offer little or no guidance. Lesh et al, who articulated the model-eliciting approach, provide the six principles that any model-eliciting activity should address (Lesh et al., 2000). McDermott and her research colleagues recommend basing questions for students on careful physics education research (McDermott, 1996; McDermott & Shaffer, 1992, 2002; Shaffer & McDermott, 1992; Trowbridge & McDermott, 1980, 1981). Middlecamp suggests that challenges should be connected with sustainability (American Chemical Society, 2009). Given the diversity of scenario-based approaches, evidence for any one approach may be not transferrable to other approaches.

When evaluated against implementation standards, scenario-based approaches have been shown through multiple examples to be applicable to a wide variety of STEM courses, and they can be implemented, depending on the nature of the problems, projects or challenges selected, within the resource constraints of most institutions. If the challenges require artifact construction or extensive interaction with external clients, resource requirements may be more difficult to address. Further, using scenario-based approaches requires that faculty members rethink their approach of "I must teach this before I teach that" to focus on developing appropriate challenges, questions, or problems, and then organizing student learning around these. The POGIL (POGIL, 2008), Physics by Inquiry (McDermott, 1996), and Chemistry in Context (American Chemical Society, 2009) projects have developed textbooks for faculty members that want to adopt these approaches in chemistry and physics courses, so these lighten the development burden. For other approaches and courses, faculty must develop their own challenges and instructional approaches. With these considerations, scenario-based approaches have good to strong support when evaluated against the implementation standards.

When evaluated against student performance standards, there are many studies that provide evidence for improved student performance for different approaches. Problem-based learning has been extensively studied in medical schools (Dochy, M., Van den Bossche, & Gijbels, 2003; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Vernon & Blake, 1993). Also, Capon and Kuhn offer another quasi-experimental study (Capon & Kuhn, 2004) that supports improvements in student learning when using problem-based learning. The VaNTH project offers a quasi-experimental study to support improved student learning with respect to more challenging problems (Roselli & Brophy, 2006). The POGIL project, which emphasizes a guided inquiry approach, has published at least two studies that provide evidence for improved student performance when compared to more traditional approaches (Farrell, Moog, & Spencer, 1999; Lewis & Lewis, 2005). Overall, the evidence for scenario-based approaches is strong, but not as compelling as the practice of organizing students in small groups. Furthermore, faculty members who apply scenario-based approaches very frequently organize their students in small groups; therefore, as Prince and Felder (Prince & Felder, 2006) have noted, it may be difficult to separate influences of using small groups from the influences of using scenario-based approaches.

Promising Practice No. 5: Providing Students Feedback through Systematic Formative Assessment

Ericsson et al (1993) highlighted the importance of what they described as deliberate practice in development of expertise in a wide variety of fields and emphasized the importance of feedback. One facet of deliberate practice that distinguishes it from mere practice or repetition is the emphasis on feedback to improve performance. In contrast to traditional practices in STEM courses of providing feedback by returning homework and exams, the fifth promising practice stresses the role of a systematic plan for formative assessment (i.e., assessment whose primary purpose is providing data for improvement as opposed to evaluation). A widely used approach that provides feedback to students about their learning is classroom response systems (Fies & Marshall, 2006), which is an element of peer instruction (Mazur, 1997) and question-driven instruction (Beatty et al., 2006). Another example of a systematic plan of formative assessment is the minute paper (Angelo & Cross, 1993; Stead, 2005) in which faculty members regularly ask students at the end of classroom sessions to address two questions that are similar to “What was the most important point that you took away from the lecture today?” and “What point for you remains the most unclear?” Faculty members review student responses and, in the next class period, present a brief summary of the responses and how they plan to address frequently mentioned fuzzy points. Stead (2005) cites at least two quasi-experimental studies that demonstrate the positive influence of the minute paper practice on student learning (Almer, Jones, & Moeckel, 1998; Chizmar & Ostrosky, 1998). Stimulated by the success of the seven principles for undergraduate education by Chickering and Gamson (1987), Nicol and Macfarlane (2006) offer seven principles for developing effective feedback plans.

In terms of implementation standards, systematic plans for formative assessment are very relevant to STEM courses (as judged by the number of reports of the use of classroom response systems and minute papers in STEM courses), can be implemented within the limits of almost any classroom setting, and require relatively minor changes by faculty members. Perhaps the most difficult change for faculty members is shifting classroom time away from communicating information via lecture and investing that time in providing feedback to students. Therefore, this promising practice could be adopted by almost every STEM faculty member and is strongly supported by the implementation standards. Even so, additional research that offered more published, supported alternative approaches, in addition to classroom assessment techniques (Angelo & Cross, 1993), for providing systematic formative assessment and feedback to students would enhance ease of implementation.

When evaluated against student performance standards, support for this practice is limited compared to small groups (Promising Practice No. 2), actively engaging students (Promising Practice No. 6), and scenario-based content organization (Promising Practice No. 4). In its report on educational assessment, the National Research Council noted that a "recent review (Black and Wiliam, 1998) revealed that classroom-based formative assessment, when appropriately used, can positively affect learning.....students learn more when they receive feedback about particular qualities of their work, along with advice on what they can do to improve" (National Research Council, 2001). However, outside of the studies reported in Black and Wiliam (1998) and the studies on the minute paper mentioned earlier, the author is unaware of other studies that provide evidence to support positive influences of systematic formative assessment on student performance. The ten-year study of peer instruction (Crouch & Mazur, 2001) shows many positive influences, but the extent to which feedback to students plays a role in improved student performance is unclear. Therefore, this promising practice has less evidence to support improved student performance than some of the other promising practices offered in this paper. However, although many of the other promising practices (e.g., active learning strategies and small group strategies) often provide formative feedback to students, the comparative studies on these strategies have not extracted whether it is the active engagement of students in learning or the formative feedback that results in improved performances. Discerning answers to these questions highlights a need for more and different kinds of research.

Promising Practice No. 6: Designing In-class Activities to Actively Engage Students

Faculty members teaching STEM courses make many decisions that affect student learning, but choices regarding in-class activities are the most visible and convey multiple messages to students about learning and how to learn. While the most common decision is exclusive use of lecture, there are multiple alternatives that more actively and explicitly involve students and that can be used for portions of every classroom session (Bonwell & Eison, 1991; Laws, Sokoloff, & Thornton, 1999; A. C. Smith et al., 2005; Sokoloff, Laws, & Thornton, 2007).

Evaluated against implementation standards, active learning strategies are relevant for all STEM courses, can be implemented in almost any learning environment, and can be adopted initially with small changes on the part of faculty members (Allen & Tanner, 2005; Smith, Sheppard, Johnson, & Johnson, 2005). Frequently expressed concerns about using active learning strategies, which include content coverage (J. L. Cooper et al., 2000; M. M. Cooper, 1995; Felder & Brent, 1999; Knight & Wood, 2005; Tien et al., 2001) and applicability to large enrollment courses, have been addressed by multiple practitioners. For content coverage, Ruhl, Hughes and Schloss (1987) showed that students in courses in which faculty members paused at intervals and talked six minutes less per lecture performed significantly better on the same exam than students in courses where faculty lectured the entire time. Knight and Wood (2005) in a quasi-experimental comparison of two implementations of developmental biology showed "significantly higher learning gains [using both pretests and posttests and homework problems] and better conceptual understanding" in the version of the course in which there was less lecture and more student participation. Felder and Brent (1999) offer an approach that STEM faculty members can use to cover content, and Cooper et al (2000) state that faculty members who used active engagement strategies and were interviewed for their study "expressed consistent satisfaction that students in their classes are demonstrating one or more of these indicators of increased learning: much greater conceptual understanding, more complex critical-thinking skills, better class attendance, more independence in lab settings, and greater confidence." Several authors (Allen & Tanner, 2005; J. L. Cooper & Robinson, 2000; Felder, 1997; Knight & Wood, 2005; Michaelson et al., 2004; Science Education Resource Center, 2008) have offered approaches that faculty members can use in large classes, including bookend lectures (K. A. Smith et al., 2005), brief, thoughtful tasks (Felder, 1997), think-pair-share (Lyman, 1981), and peer instruction (Mazur, 1997). Use of active learning strategies is strongly supported in terms of the implementation standards.

In addition to the evidence presented for the promising practice of using small groups, which almost invariably involves using learning activities that explicitly engage students, there is additional evidence for using actively learning strategies. Additional evidence includes a review article (Michael, 2006) and multiple quasi-experimental studies (Burrowes, 2003; Cummings, Marx, Thornton, & Kuhl, 1999; Freeman et al., 2007; Hoellwarth, Moelter, & Knight, 2005; Knight & Wood, 2005; Laws et al., 1999; Redish, Saul, & Steinberg, 1997). Support, when evaluated in terms of the student performance standards, for in-class active learning strategies is the strongest of the eight promising practices presented in the paper.

Promising Practice No. 7: Undergraduate Research

An undergraduate research experience (URE), in which an undergraduate student works on a research project with the guidance of a faculty member, currently is offered as a supplement to the traditional undergraduate curriculum. However, it is possible to conceive of STEM curricula in which undergraduate research experiences play an integral part. In these hypothetical cases, UREs provide an alternative for many of the decisions in the framework set forth at the outset of this paper.

If UREs are viewed as supplements to STEM curricula for a small number of select students, then UREs would be evaluated very highly in terms of the implementation standards. Since they are offered throughout STEM disciplines, they are relevant. UREs are offered at many different types of institutions, and many STEM faculty members do serve as mentors for undergraduate students. However, if UREs are viewed as an integral part of STEM curricula, then the resources required for offering UREs for large student populations are available at very few institutions. In this case, they would be evaluated as no more than fair against the implementation standards.

In terms of student performance standards, studies of the influences of UREs are available (Hunter, Laursen, & Seymour, 2007; Kardash, 2000; Lopatto, 2004; Russell, 2007; Seymour, Hunter, Laursen, & Diatonic, 2004). Evidence in these about student performance was gathered via surveys of student reports or interviews with students about their undergraduate research experiences. As far as the author knows, there are no comparisons of student learning between students with undergraduate research experiences and those without. In addition to the evidence cited in the studies about student learning, there is evidence that suggests that undergraduate research experiences have had positive influences on student decisions about whether to attend graduate school (Seymour et al., 2004). In summary, support for undergraduate research in terms of student performance standards is fair.

Promising Practice No. 8: Faculty-initiated Approaches to Student-faculty Interactions

Umbach and Wawrzynski (2005) have stated that several studies "(Astin, 1993; Ewell & Jones, 1996; Pascarella & Terenzini, 1991; Tinto, 1993, 2000) documented the strong association of both formal and informal faculty–student contact to enhanced student learning." Furthermore, student-faculty interactions "were frequently the best predictors of student persistence (Braxton et al., 1997; Hurtado & Carter, 1997; Pascarella & Terenzini, 1991; Stage & Hossler, 2000)" (Umbach & Wawrzynski, 2005). Since faculty-student interactions are an important factor in learning and persistence, faculty members could take the initiative in making connections with their students instead of waiting for students to visit them during office hours when there is a problem. Faculty members might make an assignment in which each student is expected drop by the office for a short, get-acquainted visit during the first two weeks of class. Then, interaction might be maintained through multiple communication channels including email, chat, and face-to-face talks.

In terms of the implementation standards, faculty-initiated student-faculty interactions are rated highly, except perhaps in large classes where even short visits multiplied by the number of students result in an exceptional time commitment. For large classes, alternatives to a faculty member contacting every individual student may be required.

To the author's knowledge, there are no comparison studies supporting faculty-initiated contact, but the importance of student-faculty interactions as substantiated by the references provided in the opening paragraph for this subsection suggests the positive influence this promising practice might have on student performance. Using the student performance standards, this promising practice is rated as fair.

Conclusions

Eight promising practices have been offered that provide support (to different degrees) alternatives for critical decisions that faculty members need to make as they construct their courses. A summary of the eight promising practices and their ratings against the two sets of standards is provided in Table 4.

Table 4. Summary of the Promising Practices and their Evaluations

Promising Practice	Rating with Respect to Implementation Standards	Rating with Respect to Student Performance Standards
Promising Practice No. 1: Prepare a Set of Learning Outcomes	Strong	Good
Promising Practice No. 2: Organize Students in Small Groups	Strong	Strong
Promising Practice No. 3: Organize Students in Learning Communities	Fair	Fair to Good
Promising Practice No. 4: Scenario-based Content Organization	Good to Strong	Good
Promising Practice No. 5: Providing Students Feedback through Systematic Formative Assessment	Strong	Good
Promising Practice No. 6: Designing In-class Activities to Actively Engage Students	Strong	Strong
Promising Practice No. 7: Undergraduate Research	Strong or Fair	Fair
Promising Practice No. 8: Faculty-initiated Approaches to Student-faculty Interactions	Strong	Fair

The eight promising practices presented in this paper are not intended to include all the potential practices for improving undergraduate STEM education, but they offer a solid starting point.

Acknowledgement

Valuable feedback from several colleagues has helped to improve this white paper, and the author would like to take this opportunity to express his genuine appreciation for their critiques and suggestions. These include Nancy Simpson, Ronald Ulseth and Margaret Hilton.

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