Understanding Student Differences

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Abstract

Students have different levels of motivation, different attitudes about teaching and learning, and different responses to specific classroom environments and instructional practices. The more thoroughly instructors understand the differences, the better chance they have of meeting the diverse learning needs of all of their students. Three categories of diversity that have been shown to have important implications for teaching and learning are differences in students' learning styles (characteristic ways of taking in and processing information), approaches to learning (surface, deep, and strategic), and intellectual development levels (attitudes about the nature of knowledge and how it should be acquired and evaluated). This article reviews models that have been developed for each of these categories, outlines their pedagogical implications, and suggests areas for further study.

Keywords: learning styles, approaches to learning, intellectual development

Instruction begins when you, the teacher, learn from the learner. Put yourself in his place so that you may understand what he learns and the way he understands it. (Kierkegaard)

I. Three Facets of Student Diversity

Declining interest in engineering among high school students in recent years has led to steep enrollment decreases in many engineering programs. Although the problem has been exacerbated by high student dropout rates that have characterized engineering curricula for decades, many engineering faculty members continue to view the attrition positively, believing the dropouts are mainly weak students who are unqualified to become engineers. This belief is wrong. In their classic study *Talking about Leaving* [1], Seymour and Hewitt showed that grade distributions of students who leave technical curricula are essentially the same as the distributions of those who stay in. While many of those who drop out do so because of academic difficulties, many others are good students who leave because of dissatisfaction with their instruction, a fact made graphically clear in comments quoted by Seymour and Hewitt.

Faculty complaints about students who remain in engineering through graduation are also commonly heard, with many of the complaints being variations of "They can memorize and plug numbers into formulas but they don't know how to think!" And yet, most engineering departments have one or more faculty members who manage to get many of those same students to perform at remarkably high levels, displaying first-rate problem-solving and critical and creative thinking skills. Skill deficiencies observed in engineering graduates must therefore also be attributable in part to what instructors are doing or failing to do.

An implication of these observations is that to reduce enrollment attrition and improve the thinking and problem-solving skills of engineering graduates, engineering schools should attempt to improve the quality of their teaching, which in turn requires understanding the learning needs of today's engineering students and designing instruction to meet those needs. The problem is that no two students are alike. They have different backgrounds, strengths and weaknesses, interests, ambitions, senses of responsibility, levels of motivation, and approaches to studying. Teaching methods also vary. Some instructors mainly lecture, while others spend more time on demonstrations or activities; some focus on principles and others on applications; some emphasize memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation but also by the compatibility of the student's attributes as a learner and the instructor's teaching style.

This is not to say that instructors should determine their students' individual learning attributes and teach each student exclusively in the manner best suited to those attributes. It is not possible to discover everything that affects what a student learns in a class, and even if instructors could, they would not be able to figure out the optimum teaching style for that student—the task would be far too complex. Moreover, even if a teacher knew the optimum teaching styles for all students in a class, it would be impossible to implement them simultaneously in a class of more than two students.

If it is pointless to consider tailoring instruction to each individual student, it is equally misguided to imagine that a single one-size-fits-all approach to teaching can meet the needs of every student. Unfortunately, a single approach has dominated engineering education since its inception: the professor lectures and the students attempt to absorb the lecture content and reproduce it in examinations. That particular size fits almost nobody: it violates virtually every principle of effective instruction established by modern cognitive science and educational psychology [2–5]. Any other approach that targets only one type of student would probably be more effective, but it would still fail to address the needs of most students. It follows that if completely individualized instruction is impractical and one-size-fits-all is ineffective for most students, a more balanced approach that attempts to accommodate the diverse needs of the students in a class at least some of the time is the best an instructor can do.

Diversity in education usually refers to the effects of gender and ethnicity on student performance. Those effects are important and are considered elsewhere in this journal issue [6]. This article examines three other important aspects of student diversity:

- **Learning Styles.** Learning styles are "characteristic cognitive, affective, and psychological behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment" [7]. The concept of learning styles has been applied to a wide variety of student attributes and differences. Some students are comfortable with theories and abstractions; others feel much more at home with facts and observable phenomena; some prefer active learning and others lean toward introspection; some prefer visual presentation of information and others prefer verbal explanations. One learning style is neither preferable nor inferior to another, but is simply different, with different characteristic strengths and weaknesses. A goal of instruction should be to equip students with the skills associated with every learning style category, regardless of the students' personal preferences, since they will need all of those skills to function effectively as professionals.
- **Approaches to Learning and Orientations to Studying.** Students may be inclined to approach their courses in one of three ways [8]. Those with a *reproducing orientation* tend to take a *surface approach* to learning, relying on rote memorization and mechanical formula substitution and making little or no effort to understand the material being taught. Those with a *meaning orientation* tend to adopt a *deep approach*, probing and questioning and exploring the limits of applicability of new material. Those with an *achieving orientation* tend to use a *strategic approach*, doing whatever is necessary to get the highest grade they can, taking a surface approach if that suffices and a deep approach when necessary. A goal of instruction should be to induce students to adopt a deep approach to subjects that are important for their professional or personal development.
- **Intellectual Development.** Most students undergo a developmental progression from a belief in the certainty of knowledge and the omniscience of authorities to an acknowledgment of the uncertainty and contextual nature of knowledge, acceptance of personal responsibility for determining truth, inclination and ability to gather supporting evidence for judgments, and openness to change if new evidence is forthcoming. At the highest developmental level normally seen in college students (but not in many of them), individuals display thinking patterns resembling those of expert scientists and engineers. A goal of instruction should be to advance students to that level by the time they graduate.

In this article, we outline models of student learning style preferences, orientations to studying, and levels of intellectual development; review the implications of the models for engineering education; and suggest promising avenues for future study. Before doing so, we briefly discuss the topic of assessment instrument validation, a research issue central to all three of these diversity domains.

II. A Note on Validation

Much of this paper describes assessments of various student attributes and inferences that have been drawn from the data. Before too much stock is placed in such inferences, the instrument used to collect the data should be shown to be *reliable* (consistent results are obtained in repeated assessments) and *valid* (the instrument measures what it is intended to measure).

In another paper in this issue, Olds, Moskal, and Miller [9] offer a good introduction to reliability and validity analysis. Some of the measures of reliability and validity they discuss that are applicable to instruments of the types we will describe are these:

- *Test-retest reliability:* the extent to which test results for an individual are stable over time.
- *Internal consistency reliability:* the homogeneity of items intended to measure the same quantity—that is, the extent to which responses to the items are correlated.
- *Scale orthogonality:* the extent to which the different scales of the instrument (if there are two or more scales) are independent.
- *Construct validity:* the extent to which an instrument actually measures the attribute it purports to measure. The instrument scores are said to have *convergent* validity if they correlate with quantities with which they should correlate and *divergent* or *discriminant* validity if they fail to correlate with quantities with which there is no reason to expect correlation.

Reliability and validity data of these types are readily obtainable for some of the instruments to be discussed, while for others (notably several of the learning style assessment instruments) they are difficult or impossible to find. At the end of each of sections III (Learning Styles), IV (Approaches to Learning), and V (Levels of Intellectual Development), we offer lists of potential research questions. To each list might be added the following two-part question: *If an assessment instrument is used to study any of the preceding questions, what reliability and validity data support its use (a) in general, and (b) for the population studied?*

III. Learning Styles

Students are characterized by different *learning* styles, preferentially focusing on different types of information and tending to operate on perceived information in different ways [10, 11]. To reduce attrition and improve skill development in engineering, instruction should be designed to meet the needs of students whose learning styles are neglected by traditional engineering pedagogy [12–14].

Several dozen learning style models have been developed, five of which have been the subject of studies in the engineering education literature. The best known of these models is Jung's Theory of Psychological Type as operationalized by the Myers-Briggs Type Indicator (MBTI). Strictly speaking, the MBTI assesses personality types, but MBTI profiles are known to have strong learning style implications [14–16]. This instrument was the basis for a multi-campus study of engineering students in the 1970s and 1980s and a number of other engineering-related studies since then [17–24]. Other models that have been applied extensively to engineering are those of Kolb [12, 14, 25–31], and Felder and Silverman [13, 14, 32–40]. We discuss these three models in the sections that follow. Two other models that have been used in engineering are those of Herrmann [14, 41–43], and Dunn and Dunn [44–46]. Relatively little assessment has been performed on the applicability of these models to instructional design in engineering, and we do not discuss the models further in this paper. For information about them, see the cited references.

Before we look at specific models, we should note that the concept of learning styles is not universally accepted. The simple mention of the term arouses strong emotional reactions in many members of the academic community (notably but not exclusively the psychologists), who argue that learning style models have no sound theoretical basis and that the instruments used to assess learning styles have not been appropriately validated. On the other hand, the studies summarized in the sections that follow paint a clear and consistent picture of learning style differences and their effects on student performance and attitudes. Additionally, instruction designed to address a broad spectrum of learning styles has consistently proved to be more effective than traditional instruction, which focuses on a narrow range of styles. We therefore propose taking an engineering approach to learning styles, regarding them as useful heuristics for understanding students and designing effective instruction, and continuing to use them until demonstrably better heuristics appear.

A. The Myers-Briggs Type Indicator

People are classified on the Myers-Briggs Type Indicator® (MBTI) according to their preferences on four scales derived from Jung's Theory of Psychological Types [15]:

- *extraverts* (try things out, focus on the outer world of people) or *introverts* (think things through, focus on the inner world of ideas).
- *sensors* (practical, detail-oriented, focus on facts and procedures) or *intuitors* (imaginative, concept-oriented, focus on meanings and possibilities).
- *thinkers* (skeptical, tend to make decisions based on logic and rules) or *feelers* (appreciative, tend to make decisions based on personal and humanistic considerations).
- *judgers* (set and follow agendas, seek closure even with incomplete data) or *perceivers* (adapt to changing circumstances, postpone reaching closure to obtain more data).

Lawrence [15] characterizes the preferences, strengths, and weaknesses of each of the 16 MBTI types in many areas of student functioning and offers numerous suggestions for addressing the learning needs of students of all types, and Pittenger [16] reviews research based on the MBTI.

Most engineering instruction is oriented toward introverts (lecturing and individual assignments rather than active class involvement and cooperative learning), intuitors (emphasis on science and math fundamentals rather than engineering applications and operations), thinkers (emphasis on objective analysis rather than interpersonal considerations in decision-making), and judgers (emphasis on following the syllabus and meeting assignment deadlines rather than on exploration of ideas and creative problem solving). In 1980, a consortium of eight universities and the Center for Applications of Psychological Type was formed to study the role of personality type in engineering education. Predictably, introverts, intuitors, thinkers, and judgers generally outperformed extraverts, sensors, feelers, and perceivers in the population studied [19, 21]. In work done as part of this study, Godleski [20] reported on grades in four sections of the introductory chemical engineering course at Cleveland State University taught by three different instructors. The emphasis in this course is on setting up and solving a wide variety of problems of increasing complexity, with memory and rote substitution in formulas playing a relatively small role. Intuitors would be expected to be at an advantage in this course, and the average grade for the intuitors in all sections was indeed higher than that for sensors. Godleski obtained similar results for other courses that emphasized intuitive skills, while in the few "solid sensing" courses in the curriculum (such as engineering economics, which tends to be formula-driven) the sensors scored higher.

In a longitudinal study carried out at the University of Western Ontario by Rosati [22, 23], male introverts, intuitors, thinkers, and judgers at the low end of the academic spectrum were found to be more likely to succeed in the first year of the engineering curriculum than were their extraverted, sensing, feeling, and perceiving counterparts. Rosati also observed that the introverts, thinkers, and judgers in the low-performance male population were more likely than the extraverts, feelers, and perceivers to graduate in engineering after four years, although the sensors were more likely than the intuitors to do so. No statistically significant type differences were found for academically strong male students or for female students.

As part of another longitudinal study, Felder [24] administered the MBTI to a group of 116 students taking the introductory chemical engineering course at North Carolina State University. That course and four subsequent chemical engineering courses were taught in a manner that emphasized active and cooperative learning, and type differences in various academic performance measures and attitudes were noted as the students progressed through the curriculum. The results were remarkably consistent with expectations based on type theory:

- Intuitors performed significantly better than sensors in courses with a high level of abstract content, and the converse was observed in courses of a more practical nature. Thinkers consistently outperformed feelers in the relatively impersonal environment of the engineering curriculum, and feelers were more likely to drop out of the curriculum even if they were doing well academically. Faced with the heavy time demands of the curriculum and the corresponding need to manage their time carefully, judgers consistently outperformed perceivers.
- Extraverts reacted more positively than introverts when first confronted with the requirement that they work in groups on homework. (By the end of the study, both groups almost unanimously favored group work.)
- The balanced instruction provided in the experimental course sequence appeared to reduce or eliminate the performance differences previously noted between sensors and intuitors and between extraverts and introverts.
- Intuitors were three times more likely than sensors to give themselves top ratings for creative problem-solving ability and to place a high value on doing creative work in their careers.
- The majority of sensors intended to work as engineers in large corporations, while a much higher percentage of intuitors planned to work for small companies or to go to graduate school and work in research. Feelers placed a higher value on doing socially important or beneficial work in their careers than thinkers did.

Very few results failed to confirm expectations from type theory, and most of the failures involved type differences that might have been expected to be significant but were not. The conclusion was that the MBTI effectively characterizes differences in the ways engineering students approach learning tasks, respond to different forms of instruction and classroom environments, and formulate career goals.

B. Kolb's Experiential Learning Model

In Kolb's model, students are classified as having a preference for (a) *concrete experience or abstract conceptualization* (how they take information in) and (b) a*ctive experimentation or reflective observation* (how they process information) [12, 25]. The four types of learners in this classification scheme are:

- *Type 1* (concrete, reflective)—*the diverger*. Type 1 learners respond well to explanations of how course material relates to their experience, interests, and future careers. Their characteristic question is "*Why*?" To be effective with Type 1 students, the instructor should function as a *motivator*.
- *Type 2* (abstract, reflective)—the *assimilator*. Type 2 learners respond to information presented in an organized, logical fashion and benefit if they are given time for reflection. Their characteristic question is "*What*?" To be effective, the instructor should function as an *expert.*
- *Type 3* (abstract, active)—the *converger*. Type 3 learners respond to having opportunities to work actively on well-defined tasks and to learn by trial-and-error in an environment that allows them to fail safely. Their characteristic question is "*How?*" To be effective, the instructor should function as a *coach*, providing guided practice and feedback in the methods being taught.
- *Type 4* (concrete, active)—the *accommodator*. Type 4 learners like applying course material in new situations to solve real problems. Their characteristic question is "*What if ?*" To be effective, the instructor should pose open-ended questions and then get out of the way, maximizing opportunities for the students to discover things for themselves. Problem-based learning is an ideal pedagogical strategy for these students.

Preferences on this scale are assessed with the *Learning Style Inventory®* (McBer and Company, Boston) or the *Learning Type Measure®* (About Learning Inc., Wauconda, Ill.). Most studies of engineering students based on the Kolb model find that the majority of the subjects are Types 2 and 3. For example, Sharp [26] reports that of 1,013 engineering students she tested, 40 percent were Type 3, 39 percent Type 2, 13 percent Type 4, and 8 percent Type 1. Bernold et al. [27] found that of the 350 students in their study, 55 percent were Type 3, 22 percent Type 2, 13 percent Type 4, and 10 percent Type 1.

Traditional science and engineering instruction focuses almost exclusively on lecturing, a style comfortable for only Type 2 learners. Effective instruction involves *teaching around the cycle*—motivating each new topic (Type 1), presenting the basic information and methods associated with the topic (Type 2), providing opportunities for practice in the methods (Type 3), and encouraging exploration of applications (Type 4).

A faculty training program based on the Kolb learning style model was initiated at Brigham Young University in 1989 [28]. About a third of the engineering faculty was trained in teaching around the cycle. The volunteers implemented the approach in their courses, reviewed videotapes of their teaching, and discussed their successes and problems in focus groups. Many courses were redesigned; instructors—including a number who did not participate in the original training—used a variety of teaching methods in addition to formal lecturing; discussions about teaching became a regular part of department faculty meetings; and several faculty members presented and published education-related papers. Articles describing the program do not indicate the extent to which the modified instruction led to improved learning.

Bernold et al. [27] describe an experiment at North Carolina State University in which one group of students was subjected to teaching around the cycle (in their term, "holistic instruction"), another was taught traditionally, and the course grades earned by the two groups were compared. Although the results were not conclusive, they appeared to indicate that Types 1 and 4 students were more likely to get low grades than the more numerous Types 2 and 3 students when teaching was traditional, and that holistic instruction may have helped a more diverse group of students to succeed. Spurlin et al. [29] report on an ongoing study comparing freshman engineering students of the four Kolb types. Their preliminary results also show Types 2 and 3 students doing better academically, and they are conducting further studies intended to pinpoint reasons for the relatively poor performance and high risk of attrition of the Types 1 and 4 students.

Julie Sharp of Vanderbilt University has used the Kolb model in several ways as the basis for instructional design. Her work includes the development of a variety of "writing to learn" assignments that should be effective for each of the four Kolb types [30] and applications of the model to instruction in communications and teamwork [26, 31].

C. The Felder-Silverman Model

1) Model Categories. According to a model developed by Felder and Silverman [13, 32], a student's learning style may be defined by the answers to four questions:

1. What type of information does the student preferentially perceive: *sensory* (sights, sounds, physical sensations) or *intuitive* (memories, thoughts, insights)? Sensing learners tend to be concrete, practical, methodical, and oriented toward facts and hands-on procedures. Intuitive learners are more comfortable with abstractions (theories, mathematical models) and are more likely to be rapid and innovative problem solvers [47]. This scale is identical to the sensing-intuitive scale of the Myers-Briggs Type Indicator.
2. What type of sensory information is most effectively perceived: *visual* (pictures, diagrams, flow charts, demonstrations) or *verbal* (written and spoken explanations)?
3. How does the student prefer to process information: *actively* (through engagement in physical activity or discussion) or *reflectively* (through introspection)? This scale is identical to the active-reflective scale of the Kolb model and is related to the extravert-introvert scale of the MBTI.
4. How does the student characteristically progress toward understanding: *sequentially* (in a logical progression of incremental steps) or *globally* (in large "big picture" jumps)? Sequential learners tend to think in a linear manner and are able to function with only partial understanding of material they have been taught. Global learners think in a systems-oriented manner, and may have trouble applying new material until they fully understand it and see how it relates to material they already know about and understand. Once they grasp the big picture, however, their holistic perspective enables them to see innovative solutions to problems that sequential learners might take much longer to reach, if they get there at all [48].

More detailed descriptions of the attributes of the different model categories and the nature and consequences of learning and teaching style mismatches are given by Felder and Silverman [13] and Felder [32]. Zywno and Waalen [36] report on the development and successful implementation of hypermedia instruction designed to address the learning needs of styles less favored by

POPULATION[a]	A	S	Vs	Sq	N	Reference
Iowa State, Materials Engr.	**63%**	**67%**	**85%**	**58%**	**129**	**Constant [51]**
Michigan Tech, Env. Engr.	**56%**	**63%**	**74%**	**53%**	**83**	**Paterson [52]**
Oxford Brookes Univ. , Business	64%	70%	68%	64%	63	**De Vita [53]**
British students	**85%**	**86%**	**52%**	**76%**	**21**	
International students	52%	62%	76%	52%	42	
Ryerson Univ., Elec. Engr.						
Students (2000)	**53%**	**66%**	**86%**	**72%**	**87**	**Zywno & Waalen [36]**
Students (2001)	**60%**	**66%**	**89%**	**59%**	**119**	**Zywno [38]**
Students (2002)	**63%**	**63%**	**89%**	**58%**	**132**	**Zywno [54]**
Faculty	**38%**	**42%**	**94%**	**35%**	**48**	"
Tulane, Engr.						
Second-Year Students	**62%**	**60%**	**88%**	**48%**	**245**	**Livesay *et al.* [37]**
First-Year Students	**56%**	**46%**	**83%**	**56%**	**192**	**Dee *et al.* [39]**
Universities in Belo Horizonte (Brazil)[b]						Lopes [55]
Sciences	65%	81%	79%	67%	214	
Humanities	52%	62%	39%	62%	235	
Univ. of Limerick, Mfg. Engr.	**70%**	**78%**	**91%**	**58%**	**167**	**Seery *et al.* [56]**
Univ. of Michigan, Chem. Engr.	**67%**	**57%**	**69%**	**71%**	**143**	**Montgomery [57]**
Univ. of Puerto Rico-Mayaguez						
Biology (Semester 1)	65%	77%	74%	83%	39	Buxeda & Moore [58]
Biology (Semester 2)	51%	69%	66%	85%	37	"
Biology (Semester 3)	56%	78%	77%	74%	32	"
Elect. & Comp. Engr.	47%	61%	82%	67%	?	Buxeda *et al.* [59]
Univ. of São Paulo, Engr.[b]	60%	74%	79%	50%	351	Kuri & Truzzi [60]
Civil Engr.	69%	86%	76%	54%	110	
Elec. Engr.	57%	68%	80%	51%	91	
Mech. Engr.	53%	67%	84%	45%	94	
Indust. Engr.	66%	70%	73%	50%	56	
Univ. of Technology Kingston, Jamaica	**55%**	**60%**	**70%**	**55%**	**?**	**Smith *et al.* [61]**
Univ. of Western Ontario, Engr.[c]	69%	59%	80%	67%	858	Rosati [35]
First year engr	66%	59%	78%	69%	499	Rosati [34]
Fourth year engr.	72%	58%	81%	63%	359	"
Engr. faculty	51%	40%	94%	53%	53	"
Engineering Student Average	**64%**	**63%**	**82%**	**60%**	**2506**	
Engineering Faculty Average	**45%**	**41%**	**94%**	**44%**	**101**	

[a]Rows in boldface denote studies using the current version of the Index of Learning Styles with native English speakers.
[b]Portuguese translation of the ILS used.
[c]Data collected with Version 1 of the ILS. (All other studies used Version 2.)

Table 1. Reported learning style preferences.

traditional instruction, and Sharp [40] describes an instructional module based on the Felder-Silverman model that makes students aware of differences in learning styles and how they may affect personal interactions, teamwork, interactions with professors, and learning difficulties and successes.

2) The Index of Learning Styles. The Index of Learning Styles® (ILS) is a forty-four-item forced-choice instrument developed in 1991 by Richard Felder and Barbara Soloman to assess preferences on the four scales of the Felder-Silverman model. In 1994 several hundred sets of responses to the initial twenty-eight-item version of the instrument were collected and subjected to factor analysis. Items that did not load significantly on single factors were discarded and replaced by new items to create the current version, which was put on the World Wide Web in 1997 [49]. The ILS is available at no cost to individuals who wish to assess their own preferences and to instructors or students who wish to use it for classroom instruction or research, and it may be licensed by non-educational organizations.

Learning style preferences of numerous students and faculty members have been determined using the Index of Learning Styles, with results summarized in Table 1 [50]. Unless otherwise indicated, the population samples shown in Table 1 are undergraduates. Thus, for example, of the 129 undergraduate engineering students who completed the ILS in a study conducted at Iowa State University, 63 percent were classified as active (A) learners (and by implication 37 percent were classified as reflective learners), 67 percent were sensing (S) learners (33 percent intuitive learners), 85 percent were visual (Vs) learners (15 percent verbal), and 58 percent were sequential (Sq) learners (42 percent global).

Table 1 illustrates several of the mismatches described by Felder and Silverman [13] between learning styles of most engineering undergraduates and traditional teaching styles in engineering education. Sixty-three percent of the undergraduates were sensors, while traditional engineering instruction tends to be heavily oriented toward intuitors, emphasizing theory and mathematical modeling over experimentation and practical applications in most courses; 82 percent of the undergraduates were visual learners, while most engineering instruction is overwhelmingly verbal, emphasizing written explanations and mathematical formulations of physical phenomena over demonstrations and visual illustrations; and 64 percent of the students were active, while most engineering courses other than laboratories rely almost exclusively on lectures and readings as the principal vehicles for transmitting information.

Table 1 also shows that 60 percent of the students assessed were sequential and traditional engineering education is heavily sequential, so this dimension does not involve the same type of mismatch observed for the others. Global students constitute a strong and important minority, however. They are the multidisciplinary thinkers, whose broad vision may enable them to become, for example, skilled researchers or chief executive officers of corporations. Unfortunately, traditional engineering education does little to provide students with the systemic perspective on individual subjects they need to function effectively, and the ones who take too long to get it by themselves are at risk academically.

Section II briefly discussed the issue of instrument validation. The Index of Learning Styles is one of the few instruments mentioned in this paper for which reliability and validity data have been collected for engineering student populations [37,50,54]. We will not provide details of the reliability analyses here; suffice it to say that all three of the studies just cited conclude that the ILS meets or exceeds accepted reliability standards for an instrument of its type. Felder and Spurlin [50] summarize results from several studies that provide evidence of both convergent and divergent construct validity. Profiles of engineering students at different institutions show a high degree of consistency with one another and differ substantially and in a predictable manner from profiles for engineering faculty and humanities students (see Table 1). Another indication of convergent validity is that preferences for sensing and active learning measured on the ILS were found to correlate with preferences for sensing and extraversion measured on the Myers-Briggs Type Indicator [33].

As noted previously, the conventional lecture-based teaching approach in engineering education favors intuitive, verbal, reflective, and sequential learners. In yet another demonstration of the construct validity of the ILS, Zywno and Waalen [36] found that on average the performance in conventionally taught courses of each of the favored types was superior to that of the less favored types, and they also found that the use of supplemental hypermedia instruction designed to address the needs of all types decreased the performance disparities. Felder and Spurlin [50], Livesay et al. [37], and Zywno [54] conclude that the ILS may be considered reliable and valid for assessing learning styles, although all three papers recommend continuing research on the instrument.

D. Pedagogical Implications and Potential Misuses of Learning Styles

Studies have shown that greater learning may occur when teaching styles match learning styles than when they are mismatched [11, 13, 62, 63], but the point of identifying learning styles is not to label individual students and tailor instruction to fit their preferences. To function effectively as engineers or members of any other profession, students will need skills characteristic of each type of learner: the powers of observation and attention to detail of the sensor and the imagination and abstract thinking ability of the intuitor; the abilities to comprehend information presented both visually and verbally, the systematic analysis skills of the sequential learner and the multidisciplinary synthesis skills of the global learner, and so on. If instruction is heavily biased toward one category of a learning style dimension, mismatched students may be too uncomfortable to learn effectively, while the students whose learning styles match the teaching style will not be helped to develop critical skills in their less preferred learning style categories [13, 14]. The optimal teaching style is a balanced one that sometimes matches students' preferences, so their discomfort level is not too great for them to learn effectively, and sometimes goes against their preferences, forcing them to stretch and grow in directions they might be inclined to avoid if given the option.

The preceding paragraph suggests what we believe to be the most important application of learning styles, which is to help instructors design a balanced teaching approach that addresses the learning needs of all of their students. Designing such an approach does not require assessing the students' learning style preferences: it is enough for instructors to select a model and attempt to address all of its categories (in Kolb model terms, to teach around the cycle), knowing that every class probably contains students with every preference [14]. Assessing the learning style profile of a class with an instrument such as the Myers-Briggs Type Indicator, the Kolb Learning Style Inventory, or the Index of Learning Styles—without being overly concerned about which students have which preferences—can provide additional support for effective instructional design. For example, knowing that a large majority of students in a class are sensing and visual learners can—and should—motivate the instructor to find concrete and visual ways to supplement the presentation of material that might normally be presented entirely abstractly and verbally. Many specific suggestions for designing instruction to address the full spectrum of learning styles are given by Felder and Silverman [13] and Lawrence [15].

What about identifying individual students' learning styles and sharing the results with them? Doing so can provide them with valuable clues about their possible strengths and weaknesses and indications of ways they might improve their academic performance. Precautions should be taken if students are told their learning styles, however. The instructor should emphasize that no learning style instrument is infallible, and if the students' perceptions of how they learn best differ from what the instrument says, they should not discount their own judgment. They should also be assured that their learning style preferences are not reliable indicators of what they are and are not capable of doing, and that people with every possible learning style can succeed in any profession or endeavor. If a student is assessed as, say, a sensing learner, it says nothing about his or her intuitive skills (or sensing skills, for that matter); it does not mean that he or she is unsuited to be an engineer or scientist or mathematician; and it does not excuse the low grade he or she made on the last exam. Instructors or advisers who use learning styles as a basis for recommending curriculum or career choices are misusing the concept and could be doing serious disservices to their students and advisees.

E. Questions for Further Study

As previously noted, learning styles are controversial, with questions commonly being raised regarding their meaning and even their existence. Much work needs to be done to resolve these questions and also to determine the validity of different learning style models for engineering students and to confirm or refute claims regarding the effectiveness of a balanced teaching approach. The following questions merit investigation:

1. Does an assessed learning style preference indicate (a) the type of instruction a student is most comfortable with or (b) the type of instruction most likely to lead to more effective learning? To what extent are the two coincident?

2. Do any learning style preferences depend on students' ethnic and cultural backgrounds? Which preferences, and what are the nature and extent of the dependences?
3. To what extent does teaching exclusively to a student's learning style preference lead to (a) greater student satisfaction, (b) improvement in skills associated with that preference, (c) lack of improvement in skills associated with the opposite preference?
4. Does a curriculum heavily biased toward a particular learning style increase the incidence of dropouts of students with conflicting styles? To what extent does more balanced instruction reduce attrition and improve academic performance of those students?
5. Is the provision of choice over learning tasks an effective strategy for accommodating different learning style preferences? How much choice should be provided and what kind?
6. How effective is instructional technology that provides alternative pathways through a body of material, with the pathways being designed to appeal to different learning style preferences?
7. How should learning style preferences be incorporated in advising? How effective are interventions that take learning style into account?
8. Does mixing learning styles when forming project teams lead to better team products? Does it lead to increased interpersonal conflict? If the answer to each question is "yes," do the improved products compensate for the greater conflict risk? Does making team members aware of their learning style differences lower the potential for conflict?
9. How helpful to students is discussion of learning styles in class?
10. To what extent are preferences on comparable scales of different instruments correlated?
11. To what extent do the answers to any of the preceding questions depend on the strength of students' learning style preferences?

IV. Approaches to Learning and Orientations to Studying

A. Definitions and Assessment

Marton and Säljö [64] define three different approaches to learning—a *surface approach, a deep approach*, and a *strategic approach*.

Students who adopt a surface approach to learning memorize facts but do not try to fit them into a larger context, and they follow routine solution procedures without trying to understand their origins and limitations. These students commonly exhibit an extrinsic motivation to learn (*I've got to learn this to pass the course, to graduate, to get a good job*) and an unquestioning acceptance of everything in the textbook and in lectures. To them, studying means scouring their texts for worked-out examples that look like the homework problems so they can simply copy the solutions. They either ignore the text outside of the examples or they scan through it with a highlighter, looking for factual information that the instructor might consider important, which they will attempt to memorize before the exam.

Students who take a deep approach do not simply rely on memorization of course material but focus instead on understanding it. They have an intrinsic motivation to learn, with intellectual curiosity rather than the possibility of external reward driving their efforts. They cast a critical eye on each statement or formula or analytical procedure they encounter in class or in the text and do whatever they think might help them understand it, such as restating text passages in their own words and trying to relate the new material to things they have previously learned or to everyday experience. Once the information makes sense, they try to fit it into a coherent body of knowledge.

Students who adopt a strategic approach do whatever it takes to get the top grade. They are well organized and efficient in their studying. They carefully assess the level of effort they need to exert to achieve their ambition, and if they can do it by staying superficial they will do so, but if the instructor's assignments and tests demand a deep approach they will respond to the demand.

A student may adopt different approaches to learning in different courses and even for different topics within a single course. An *orientation to studying* is a tendency to adopt one of the approaches in a broad range of situations and learning environments [5, 8]. Students who habitually adopt a surface approach have a *reproducing orientation*; those who usually adopt a deep approach have a *meaning orientation*; and those inclined to take a strategic approach have an *achieving orientation*. The Lancaster Approaches to Studying Questionnaire (LASQ) [65] is a sixty-four-item questionnaire that involves twelve subscales relevant to the three orientations and four additional subscales. Shorter forms of the LASQ that provide less detailed information are referenced by Woods et al. [66], and an alternative to the LASQ is the Study Process Questionnaire developed by Biggs [67].

Woods et al. [66] report on a study in which one of the short forms of the LASQ was administered to 1,387 engineering students. The strongest inclination of the students was toward a strategic approach, followed in order by a surface approach and a deep approach. Bertrand and Knapper [68] report LASQ results for students in other disciplines. Chemistry and psychology students went from a preference for strategic learning in their second year to a preference for deep learning in their fourth year, with both groups displaying consistently low inclinations toward a surface approach.

Bertrand and Knapper [68] also report on three groups of students in two multidisciplinary curricula—students in the second and fourth years of a project-based environmental resource studies program and students in a problem-based program on the impact of new materials. All three groups showed relatively strong inclinations toward a deep approach. There was little difference in the profiles of the second- and fourth-year students, suggesting that the results might reflect the orientations of the students selecting into the programs more than the influence of the programs.

There are similarities between orientations to studying and learning styles. Both represent tendencies that are situationally dependent, as opposed to fixed traits like gender or handedness that always characterize an individual. Just as a student who is a strong intuitor may function like a sensor in certain situations and vice versa, a student with a pronounced meaning orientation may under some circumstances adopt a surface approach to learning, and a strongly reproducing student may sometimes be motivated to dig deep. Similarly, just as students may be reasonably balanced in a learning style preference, frequently functioning in ways characteristic of, say, both sensors and intuitors, some students may be almost equally likely to adopt deep and surface approaches in different courses and possibly within a given course. We will shortly say more about instructional conditions that influence the choice.

B. Effects of a Deep Approach on Learning Outcomes

Researchers have assessed student approaches to learning and correlated the results with various learning outcomes [3, 5, 69]. In studies cited by Ramsden [5], students who took a deep approach to reading created comprehensive and integrated summaries of material they had read, interpreting the information rather than simply repeating it, while those who took a surface approach were more likely to recite fragments of the reading content almost randomly. The deep approach also led to longer retention of information—presumably because the information was learned in context rather than by rote memorization—and to consistently higher grades on examinations and in courses.

For example, Prosser and Millar [70] examined first-year physics students' understanding of force concepts before and after their introductory mechanics course. Eight out of nine students who took a deep approach and only two of twenty-three who used a surface approach showed significant progress in understanding force concepts, moving away from Aristotle and toward Newton. Meyer et al. [71] found that engineering students who adopted a deep approach in a course were very likely to pass the course (in fact, none of their subjects in this category failed), while students who adopted a surface approach were very likely to fail. The students who adopted a deep approach also generally expressed greater satisfaction with their instruction.

C. Motivating a Deep Approach to Learning

The approach a student might adopt in a particular situation depends on a complex array of factors. Some are intrinsic to the student (e.g., possession of prerequisite knowledge and skills and motivation to learn the subject), while others are determined more by the instructional environment (e.g., the content and clarity of the instructor's expectations and the nature and quality of the instruction and assessment).

Biggs [3] proposes that achieving desired learning outcomes requires *constructive alignment* of the elements just listed. *Alignment* means that the factors under the instructor's control are all consistent with the goal: the desired outcomes are clearly communicated to the students as expectations, instructional methods known to favor the outcomes are employed and methods that work against them are avoided, and learning assessments (homework, projects, tests, etc.) are explicitly directed toward the outcomes. *Constructive* means that the instructional design adheres to the principle of constructivism, which holds that knowledge is constructed by the learner, as opposed to being simply transmitted by a teacher and absorbed. The teacher's job is to create conditions that lead students to construct accurate representations of the concepts being studied, first abandoning prior misconceptions if any exist.

Certain features of classroom instruction have been found to be constructively aligned with the adoption of a deep approach to learning, while other features have the opposite effect [3, 5, 69]:

1. Interest in and background knowledge of the subject encourage a deep approach; lack of interest and inadequate background discourage it.
2. Clearly stated expectations and clear feedback on progress encourage a deep approach; poor or absent feedback discourages it.
3. Assessment methods that emphasize conceptual understanding encourage a deep approach; methods that emphasize recall or the application of routine procedural knowledge discourage it.
4. Teaching methods that foster active and long-term engagement with learning tasks encourage a deep approach.
5. Opportunities to exercise responsible choice in the content and method of study encourage a deep approach.
6. Stimulating and caring teaching encourages a deep approach; apathetic or inconsiderate teaching discourages it. A corollary is that students who perceive that teaching is good are more likely to adopt a deep approach than students with the opposite perception.
7. An excessive amount of material in the curriculum and an unreasonable workload discourage a deep approach.
8. Previous experiences with educational settings that encouraged deep approaches further encourage deep approaches . A similar statement can be made regarding surface approaches.

Well-established instructional strategies can be used to achieve these conditions. Inductive teaching methods such as *problem-based* and *project-based learning* [72–77] can motivate students by helping to make the subject matter relevant to their prior experience and interests (addressing item #1 above) and they also emphasize conceptual understanding and de-emphasize rote memorization (item #3). An excellent way to make expectations clear (item #2) is to articulate them in the form of instructional *objectives* [78–80]—statements of observable actions students should be able to do (define, explain, calculate, derive, model, design) once they have completed a section of a course.

Several student-centered teaching approaches accomplish the goal of actively involving students in learning tasks (item #4), notably *active learning* (engaging students in class activities other than listening to lectures) and *cooperative learning* (getting students to work in small teams on projects or homework under conditions that hold all team members accountable for the learning objectives associated with the assignment) [81–84]. Trigwell et al. [85, 86] found a positive correlation between an instructor's use of such instructional methods and students' adoption of a deep approach to learning. Other references provide numerous examples of teaching in a stimulating caring manner (item #6), providing clear feedback by, among other ways, designing appropriate tests (item #2), and providing choice in learning tasks (item #5) [4, 87–91]. Several of the references cited in this paragraph and the preceding one also summarize research connecting the instructional methods mentioned with a variety of positive learning outcomes [72, 82, 84].

D. Questions for Further Study

Of the three diversity domains discussed in this paper, approaches to learning may be the one with the most solid research base [3, 5, 69, 92]. However, little has been done thus far to apply and extend the research to engineering. Following are some of the questions that might profitably be studied:

1. What percentages of students in traditional engineering curricula are characterized by reproducing, meaning, and achieving orientations to studying?
2. Do approaches to learning and orientations to studying depend on students' ethnic and cultural backgrounds? What are the nature and extent of the dependences?

3. Does the adoption of a deep approach to learning in an engineering course lead to improved learning as it has been shown to do in other disciplines? If so, for which learning outcomes can improvements be demonstrated?
4. Do the instructional conditions and methods (e.g., active learning, cooperative learning, and problem-based learning) that purportedly motivate the adoption of a deep approach do so in engineering? How and to what extent can students with a reproducing orientation be motivated to adopt a deep approach?
5. Would one need to reduce the content or extend the length of the engineering curriculum to reduce the heavy time demands on students that have been shown to discourage the adoption of a deep approach?
6. How do students with meaning, reproducing, and achieving orientations to learning compare in high-level thinking skills, such as critical thinking and creative thinking?
7. Might discussing approaches to learning with students promote their adoption of a deep approach?

V. Levels of Intellectual Development

Many students enter college in what Kroll [93] refers to as a state of "ignorant certainty," believing that knowledge is certain, beliefs are either right or wrong, the authorities (e.g., their professors and the authors of their textbooks) have the answers, and their job is to memorize those answers and repeat them on tests. As they gain experience, most gradually progress toward a state of (again in Kroll's terminology) "intelligent confusion," in which they recognize that all knowledge is contextual, take responsibility for making their own judgments on the basis of evidence rather than relying on the word of authorities, and become relatively sophisticated at gathering and interpreting evidence from a wide range of sources. In other words, those who attain that state (which relatively few do by the time they graduate) come to think like expert scientists and engineers. This progression has been referred to as *intellectual* (or *cognitive* or *epistemological*) development.

Different levels of intellectual development constitute the third category of student diversity to be discussed here. In this section we review several models of intellectual development, discuss their applicability to engineering education, survey existing applications, and suggest areas for further exploration. Much of the material presented is drawn from a pair of articles recently published in this journal [94, 95].

A. Models of Intellectual Development

Four models of intellectual development are described in the literature. The first, Perry's Model of Intellectual Development [96,97], is the only one that has had widespread application in engineering education [98–106]. The low and intermediate levels of Perry's model are almost identical to the low and intermediate levels of the King-Kitchener Model of Reflective Judgment [97, 107, 108], which may be the most widely used and validated of the four models outside engineering education. (The two models diverge at their highest levels, which are rarely attained by college students.) In *Women's Ways of Knowing*, Belenky et al. [109] suggest that Perry's model largely characterizes men (its formulation was based almost entirely on interviews with male students) and propose an alternative progression of stages intended to characterize women's development. Baxter Magolda's Model of Epistemological Development [97, 110] integrates the preceding models by defining alternative patterns for all levels but the highest one, with one pattern characterizing more men than women and the other more women than men. Table 2 shows the levels and patterns of the Baxter Magolda model and the correspondences between that model and the other three. The paragraphs that follow discuss primarily the models of Baxter Magolda and Perry.

The developmental pattern described by all four models has the following general form. Students at the lowest levels (Baxter Magolda's *absolute knowing* and Perry's *dualism*) believe that every intellectual and moral question has one correct answer and their professors (at least the competent ones) know what it is. As the students confront challenges to their belief systems in their courses and through interactions with peers, they gradually come to believe in the validity of multiple viewpoints and concurrently decrease their reliance on the word of authorities (Baxter Magolda's *transitional* and *independent knowing* and Perry's *multiplicity*). Baxter Magolda's highest level, *contextual knowing*, which parallels Perry's *contextual relativism* (Level 5) and the early stages of *commitment in the face of uncertainty* (Level 6 and perhaps Level 7), is characterized by final rejection of the notions of the certainty of knowledge and the omniscience of authorities. Contextual knowers take responsibility for constructing knowledge for themselves, relying on both objective analysis and intuition and taking into account (but not accepting without question) the ideas of others whose expertise they acknowledge. They move away from the idea commonly held by independent knowers (Level 4 on the Perry scale) that all opinions are equally valid as long as the right method is used to arrive at them, and they acknowledge the need to base judgments on the best available evidence within the given context, even in the face of uncertainty and ambiguity.

B. Assessment of Development

In the method traditionally used to assess developmental levels, trained interviewers conduct structured open-ended interviews, the interviews are transcribed, and trained raters analyze the transcripts and assign levels to the interviewees. While this method is universally considered the most valid and reliable approach to assessment, the cost of implementing it has motivated the design of pencil-and-paper instruments that can be more easily administered and scored. The Measure of Intellectual Development (MID) for the Perry model [111] and the Measure of Epistemological Reflection (MER) for the Baxter Magolda model [112, 113] call for students to write essays on topics derived from the interview protocols, and the essays are rated in the same manner as the interview transcripts. The Learning Environment Preferences (LEP) questionnaire [114] and Reflective Thinking Appraisal [115] are Likert-scale instruments for assessing levels on the Perry and King-Kitchener models, respectively.

While pencil-and-paper instruments are easier and faster to administer than interviews, the ratings obtained tend to be one to two positions lower than ratings obtained with interviews and correlate moderately at best with interview ratings [100, 104]. To improve the correlation, Pavelich, Miller, and Olds [104] developed an online tool called Cogito, which asks questions about scenarios related to four controversial issues, asks follow-up questions based on the responses, and uses a neural net to identify response patterns and

Baxter Magolda	Absolute Knowing[a]		Transitional Knowing[b]		Independent Knowing[c]		Contextual Knowing[d]
	Mastery Pattern	Receiving Pattern	Impersonal Pattern	Interpersonal Pattern	Individual Pattern	Interindividual Pattern	
Perry	2 Late Dualism		3 Multiplicity Subordinate		4 Multiplicity		5-7 Contextual Relativism Preliminary Commitment
Belenky (Women's Ways of Knowing)		Received Knowledge		Subjective Knowledge	Procedural Knowledge: Separate Pattern	Procedural Knowledge: Connected Pattern	Constructed Knowledge
King-Kitchener	Early Prereflective Thinking		Late Prereflective Thinking		Quasi-Reflective Thinking		Reflective Thinking

[a] **Absolute knowing**. All knowledge that matters is certain; all positions are either right or wrong. Authorities have The Truth and the responsibility to communicate it, and the students' job is to memorize and repeat it. *Mastery pattern* (more men than women): Students raise questions to make sure their information is correct and challenge deviations from their view of the truth. *Receiving pattern* (more women than men): Students take in and record information passively, without questioning or challenging it.

[b] **Transitional knowing.** Some knowledge is certain and some is not. Authorities have the responsibility to communicate the certainties, and the students are responsible for making their own judgments regarding the uncertainties. *Impersonal pattern* (more men than women): Make judgments using a logical procedure prescribed by authorities. Full credit is deserved for following the right procedure, regardless of the clarity of the reasoning and the quality of the supporting evidence. *Interpersonal pattern* (more women than men): Base judgments on intuition and personal feelings; distrust logical analysis and abstract reasoning.

[c] **Independent knowing.** Most knowledge is uncertain. Students take responsibility for their own learning rather than relying heavily on authorities or personal feelings. They collect and use evidence to support judgments, but often superficially, and believe that when knowledge is uncertain all conclusions regarding it are equally good if the right procedure is used to reach them. *Individual pattern* (more men than women): Rely on objective logic, critical thinking, and challenging their own and others' positions to establish truth and make moral judgments. *Interindividual pattern* (more women than men): Rely on caring, empathy, and understanding of others' positions as bases for judgments.

[d] **Contextual knowing.** All truths are contextual. Students take responsibility for making judgments, acknowledging the need to do so in the face of uncertainty and ambiguity. They use all possible sources of evidence in the process—objective analysis and intuition, their own thoughts and feelings and ideas of others whose expertise they acknowledge—and they remain open to changing their decisions if new evidence is forthcoming.

Table 2. Models of intellectual development [94].

Year (n)	Average Perry level (SD)	% at Level 5	Reference
1 (45)	3.27 (0.44)		Pavelich & Moore [102]
2 (34)	3.71 (0.53)		
4 (46)	4.28 (0.70)	25%	
1 (21)	3.27 (0.40)	0%	Wise et al. [106]
3 (21)	3.33 (0.35)	0%	
4 (21)	4.21 (0.50)	33%	

Table 3. Perry levels of engineering students.

assign levels to them. The neural net is trained on a set of responses submitted by individuals with known levels on the Reflective Judgment and Perry models (based on structured interviews). In initial tests, the maximum correlation coefficient of about 0.5 between the interview-based levels and the Cogito-assigned levels was indeed higher than the best values obtained for the pencil-and-paper instruments, but was still well below the desired minimum value of 0.8. The authors speculated that 0.5–0.6 might be an upper bound to the correlation coefficient between ratings obtained using interviews and objectively-scored instruments.

C. Levels of Development of Engineering Students

Table 3 summarizes results of two studies in which the Perry levels of beginning and advanced engineering undergraduates were measured. Pavelich's study [102] was carried out to assess the effect on intellectual development of the strong experiential learning environment at the Colorado School of Mines. The study by Wise et al. [106] was intended to determine the effect of a first-year project-based design course at Penn State. The studies are remarkably consistent in their assessments of the initial and final average levels of the subjects. Most of the entering students were near Perry Level 3, only beginning to recognize that not all knowledge is certain and still relying heavily on authorities as sources of truth. The average change after four years of college was one level, with most of the change occurring in the last year. Neither instructional approach met its goal of elevating a significant number of students to Level 5. As discouraging as these results might seem, one could speculate that a curriculum lacking such features as the experiential learning environment at Mines or the project-based first-year experience at Penn State (in Wankat's term, a "dualistic curriculum" [91]) would lead to even less growth than was observed in the two studies in question.

Wise et al. [106] also report Perry ratings of eight male engineering students and eight female engineering students who completed the first-year project-based design course. There was initially no appreciable difference between the two groups in average Perry rating or SAT scores. At the end of the first year, the average Perry rating was 3.50 for the men and 3.16 for the women; at the end of the third year the ratings were 3.50 (men) and 3.00 (women); and at the end of the fourth year the ratings were 4.00 (men) and 4.50

(women). None of the differences were statistically significant although the differences for the third year came close ($p = 0.054$). The lack of significance could be an artifact of the small sample size. To the extent that the observed differences are real, they support the contentions of Belenky et al.[109] and Baxter Magolda [110] that men and women exhibit different patterns of development.

D. Promoting Intellectual Development

A necessary condition for students' intellectual growth is *challenge* to the beliefs that characterize their current developmental levels. An absolute knower who is never confronted with open-ended questions that have multiple solutions cannot be expected to accept the reality of multiplicity and move to transitional knowing spontaneously. Similarly, an independent knower who is not challenged for inadequate use of evidence in making judgments is not likely to make the shift to contextual knowing.

The challenge cannot be too great, however. If students are confronted with tasks that call for thinking too far above their current developmental level (in Vygotsky's term, outside their Zone of Proximal Development [116]), they may not be capable of understanding what is being required of them. Moreover, challenge alone—even at an appropriate level—may not be sufficient to move students to higher levels of development. Students confronted with challenges to their fundamental beliefs may feel threatened and either persist at their current developmental levels or retreat to even lower levels. To avoid these outcomes, instructors should provide appropriate *support* to help their students meet the challenges.

Felder and Brent [95] propose five instructional conditions that should provide the balance of challenge and support needed to promote intellectual growth and suggest numerous ways to establish the conditions. The conditions are listed in Table 4. Most of the methods suggested in [95] are supported by extensively cited references on teaching and learning [2, 3, 5, 87, 88, 90, 91], and the student-centered approaches of Condition D have repeatedly been shown to have positive effects on a wide variety of learning outcomes [119–123]. However, until a researcher implements the recommendations and assesses the intellectual development of the subjects (ideally comparing their growth with that of a control group that goes through a traditionally taught curriculum), the effectiveness of the conditions in Table 4 at promoting growth will remain speculative.

A. *Variety and choice of learning tasks* 1. Varied problem types 2. Varied levels of assignment definition and structure 3. Choice on assignments, tests, and grading policies
B. *Explicit communication and explanation of expectations* 1. Instructional objectives covering high-level tasks 2. Study guides and tests based on the objectives
C. *Modeling, practice, and constructive feedback on high-level tasks* 1. Assignment of relevant tasks and modeling of required procedures 2. Practice in assignments followed by inclusion of similar tasks on tests
D. *A student-centered instructional environment* 1. Inductive learning (problem/project based learning, guided inquiry) 2. Active and cooperative learning 3. Measures to defuse resistance to student-centered instruction
E. *Respect for students at all levels of development* 1. A sense of caring about students 2. Awareness of and respect for current levels of development while promoting higher levels

Table 4. Instructional conditions that facilitate intellectual growth [95].

E. Questions for Further Study

The study of the intellectual development of engineering students is still in a preliminary stage, with many basic questions as yet unaddressed. Several of the questions follow.

1. What intellectual development level distributions characterize most engineering students at different stages of the curriculum? Are there differences between students at different types of schools? Do levels vary with demographic or sociological factors or academic predictors such as SAT scores, and if so, how? Do levels correlate with course grades? Are the contrasting gender-related patterns of Baxter Magolda's model observed for engineering students? What levels and patterns characterize engineering faculty?
2. To what extent do levels on the different models of intellectual development actually correspond in the manner shown in Table 2? (Those correspondences are based entirely on the descriptions of the levels and not on comparative data.)
3. To what extent do the instructional conditions listed in Table 4 promote intellectual development? What other instructional conditions or methods do so, and to what extent?
4. Is Vygotsky's Zone of Proximal Development a reality in the context of intellectual development? In other words, are assertions that students cannot cope with instruction more than (say) one Perry level above their current developmental level valid, or can suitable support enable them to bridge broader cognitive gaps?
5. What are the effects of introducing students to the concept of intellectual development? For example, would being able to identify their own attitudes in the context of developmental levels promote their intellectual growth, or might explicit description of the different stages of development lead to resentment and increased resistance from students at lower levels?

VI. TEACHING TO ADDRESS ALL THREE FORMS OF DIVERSITY

Teaching strategies have been recommended to help instructors meet the needs of the full spectrum of learning styles [13, 15, 26], induce students to adopt a deep approach to learning [3, 5, 69], and promote students' intellectual development [95]. The prospect of implementing three different teaching approaches simultaneously to achieve all three goals could be intimidating to instructors, but commonalities among the three diversity domains and the instructional methods that address them make the task manageable. The basis of the discussion that follows is the set of recommendations for promoting intellectual development presented in Table 4.

Assigning a variety of learning tasks (part of Condition A of Table 4) is foremost among the methods that have been recommended to address learning goals in all three diversity domains. Variation enables instructors both to challenge the beliefs about knowledge and its acquisition that characterize different developmental levels and to ensure that students are confronted with some assignments that require a deep approach to learning. Variety in assignments is also a cornerstone of recommendations for addressing the full spectrum of learning styles, with some problems emphasizing practical considerations and requiring careful attention to details (sensing strengths) and others calling for theoretical interpretation and mathematical modeling (intuitive strengths), some involving individual efforts (reflective) and others requiring teamwork (active), and so on.

A clear similarity exists between the characteristics of a deep approach to learning and the defining attributes of Baxter Magolda's contextual knowledge level of intellectual development (Perry Level 5 and above). Both a deep approach and contextual knowing involve taking responsibility for one's own learning, questioning authorities rather than accepting their statements at face value, and attempting to understand new knowledge in the context of prior knowledge and experience. A reasonable assumption is that conditions known to promote a deep approach should also promote intellectual growth. As we noted in section IV-C, Conditions A3, B, C, D1, D2, and E1 of Table 4 have been shown to encourage a deep approach.

Inductive instructional approaches such as problem-based learning (Condition D of Table 4) should also be effective for addressing the learning goals associated with all three domains. Open-ended problems that do not have unique well-defined solutions pose a serious challenge to students' low-level beliefs in the certainty of knowledge and the role of instructors as providers of knowledge. Such problems by their very nature also require a deep approach to learning (rote memorization and simple algorithmic substitution being clearly inadequate strategies for them), and solving them eventually requires skills associated with different learning styles: the imagination and capacity for abstract thinking of the intuitor and the attention to detail of the sensor; the holistic vision of the global learner and the systematic analytical approach of the sequential learner.

Requiring students to modify their fundamental beliefs about the nature of knowledge can be unsettling or threatening, as can calling on them to adopt a deep approach to learning when they are inclined to a surface approach or to complete assignments that call for abilities not normally associated with their learning style preferences. It is reasonable to speculate that the conditions in Table 4 involving support for students should help students respond successfully to these types of challenges. Offering a choice of learning tasks (part of Condition A of Table 4), explicitly communicating expectations (Condition B), modeling and providing practice and feedback on high-level tasks (Condition C), and showing respect for students at all levels of development (Condition E) are all ways to provide support.

While these linkages among the domains may appear logical, they must be considered speculative in the absence of rigorous confirmatory analysis. Here, then, is our final list of suggested questions to explore.

1. How strong is the hypothesized link between orientation to studying and level of intellectual development? Put another way, to what extent does a student's level of intellectual development correlate with his or her tendency to adopt a deep approach to learning?
2. What correlations exist between learning styles and approaches to learning and/or levels of intellectual development? For example, are intuitors more likely than sensors and global learners more likely than sequential learners to adopt a deep approach? Are there developmental level differences between students with different learning style preferences?
3. Are there gender-related patterns in learning style preferences or orientations to studying comparable to the patterns in Baxter Magolda's Model of Epistemological Development? Are there cultural differences in any of the three diversity categories?
4. To what extent do each of the conditions listed in Table 4—including the use of student-centered instructional models such as cooperative learning and problem/project-based learning—promote intellectual growth, the adoption of a deep approach, and the development of skills associated with different learning styles in engineering students? Are there instructional methods or conditions not covered in Table 4 that would achieve the same goals?

VII. Summary

Students differ from one another in a wide variety of ways, including the types of instruction to which they respond best (learning styles), the ways they approach their studies (orientations to studying and approaches to learning), and their attitudes about the nature of knowledge and their role in constructing it (levels of intellectual development). While much has been written about all three categories of diversity in the general education literature, relatively little solid research specific to engineering education has been performed. We have suggested a number of promising areas for study:

- *Validating instruments used to assess learning styles, orientations to study, and levels of intellectual development of engineering students.* Most of the instruments listed in this paper have been subjected to reliability and validity analysis, but few of the validation studies involved engineering student populations. While results obtained with an instrument that has not been rigorously validated may be informative (especially if they are consistently replicated in independent studies), conclusions can be made and generalized with much greater confidence if the instrument has been shown to be reliable and valid for the population being studied.
- *Characterizing students.* Learning style profiles, orientations to study, and levels of intellectual development of engineering students should be assessed and analyzed. Differences in any of the three should be identified among (a) students at different levels of a single engineering curriculum, (b) students in different branches of engineering, (c) students at different types of schools (research-intensive and teaching-intensive, public and private, small and large), (d) engineering students and students in other disciplines, and (e) students and faculty.
- *Establishing correlations among the three diversity domains.* Correlations among learning styles, orientations to study, and levels of intellectual development should be identified. Correlations could be useful for instructional design—so that, for example, if the anticipated correlation between a meaning orientation to study and a contextual knowing level of development on Baxter Magolda's scale (Perry Level 5) is verified, instructors wishing to promote the intellectual development of their students could feel more confident in using methods known to promote a deep approach to learning. Moreover, confirming the existence of anticipated correlations would support the construct validity of the instruments used to assess the positions or preferences being compared.
- *Evaluating the effectiveness of instructional methods and programs.* Most engineering faculty would agree that to be effective, instruction should address the needs of students across

the full spectrum of learning styles, promote adoption of a deep approach to learning, and help students advance to higher levels of intellectual development. Many authors have proposed instructional methods for achieving one or more of those goals. What is needed is solid evidence that either supports or refutes claims of the effectiveness of those methods in achieving the desired outcomes.

We began this paper with an admonition by Kierkegaard that true instruction begins when instructors understand their students. An important component of that understanding is awareness of the different attitudes students have toward learning, the different ways they approach it, and how instructors can influence both their attitudes and approaches. The research summarized in this paper and the research that remains to be done can help instructors gain that awareness. The more successful they are in doing so, the more effectively they can design instruction that benefits all of their students. In turn, the better students understand the strengths and weaknesses associated with their attitudes and preferences, the more likely they will be to learn effectively while they are in school and throughout their careers.

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References

[1] Seymour, E., and Hewitt, H., *Talking about Leaving: Why Undergraduates Leave the Sciences*, Boulder, Colo.,: Westview Press, 1997.

[2] Bransford, J.D., Brown, A.L., and Cocking, R.R., eds., *How People Learn: Brain, Mind, Experience, and School*, Washington, D.C.: National Academy Press, 2000. Online at *http://books.nap.edu/catalog/9853.html./*

[3] Biggs, J., *Teaching for Quality Learning at University*, 2nd ed., Buckingham: The Society for Research into Higher Education and Open University Press, 2003.

[4] McKeachie, W.J., *McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers*, 11th ed., Boston, Mass.: Houghton Mifflin, 2002.

[5] Ramsden, P., *Learning to Teach in Higher Education*, 2nd ed., London: Taylor and Francis, Inc., 2003.

[6] Chubin, D.E., May, G.S., and Babco, E.L., "Diversifying the Engineering Workforce," *Journal of Engineering Education*, Vol. 94, No. 1, 2005, pp. ***-***.

[7] Keefe, J.W., "Learning Style: An Overview," in Keefe, J.W., ed., *Student Learning Styles: Diagnosing and Prescribing Programs*, Reston, Va.: National Association of Secondary School Principals, 1979.

[8] Entwistle, N., "Motivational Factors in Students' Approaches to Learning," in Schmeck, R.R., ed., *Learning Strategies and Learning Styles*, Ch. 2, New York, N.Y.: Plenum Press, 1988.

[9] Olds, B.M., Moskal, B.M., and Miller, R.L., "Assessment in Engineering Education: Evolution, Approaches, and Future Collaborations," *Journal of Engineering Education*, Vol. 94, No. 1, 2005, pp. ***-***.

[10] Corno, L., and Snow, R.E., "Adapting Teaching to Individual Differences Among Learners," in M. C. Wittrock, ed., *Handbook of Research on Teaching*, 3rd ed., New York, N.Y.: Macmillan and Co., 1986.

[11] Schmeck, R.R., ed., *Learning Strategies and Learning Styles*, New York, N.Y.: Plenum Press, 1988.

[12] Stice, J.E., "Using Kolb's Learning Cycle to Improve Student Learning," *Engineering Education*, Vol. 77, No. 5, 1987, pp. 291–296.

[13] Felder, R.M., and Silverman, L.K., "Learning and Teaching Styles in Engineering Education," *Engineering Education*, Vol. 78, No. 7, 1988, pp. 674–681. Online at *http://www.ncsu.edu/felder-public/Papers/LS-1988.pdf*.

[14] Felder, R.M., "Matters of Style," ASEE Prism, Vol. 6, No. 4, 1996, pp. 18–23. Online at *www.ncsu.edu/felder-public/Papers/LS-Prism.htm*.

[15] Lawrence, G., *People Types and Tiger Stripes: A Practical Guide to Learning Styles*, 3rd ed., Gainesville, Fla.: Center for Applications of Psychological Type, 1993.

[16] Pittenger, D.J., "The Utility of the Myers-Briggs Type Indicator," *Review of Educational Research*, Vol. 63, 1993, pp. 467–488.

[17] McCaulley, M.H., "Psychological Types of Engineering Students—Implications for Teaching," *Engineering Education*, Vol. 66, No. 7, 1976, pp. 729–736.

[18] Yokomoto, C.E., and Ware, J.R., "Improving Problem Solving Performance Using the MBTI," *Proceedings, 1982 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[19] McCaulley, M.H., Godleski, E.S., Yokomoto, C.F., Harrisberger, L., and Sloan, E.D., "Applications of Psychological Type in Engineering Education," *Engineering Education*, Vol. 73, No. 5, 1983, pp. 394–400.

[20] Godleski, E.S., "Learning Style Compatibility of Engineering Students and Faculty," *Proceedings, 1984 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[21] McCaulley, M.H., Macdaid, G.P., and Granade, J.G., "ASEE-MBTI Engineering Consortium: Report of the First Five Years," *Proceedings, 1985 ASEE Annual Conference*, Washington, D.C.: American Society for Engineering Education.

[22] Rosati, P.A., "Student Retention from First-Year Engineering Related to Personality Type," *Proceedings, 1993 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[23] Rosati, P.A., "Psychological Types of Canadian Engineering Students," *Journal of Psychological Type*, Vol. 41, 1997, pp. 33–37.

[24] Felder, R.M., Felder, G.N., and Dietz, E.J., "The Effects of Personality Type on Engineering Student Performance and Attitudes," *Journal of Engineering Education*, Vol. 91, No. 1, 2002, pp. 3–17. Online at *http://www.ncsu.edu/felder-public/Papers/longmbti.pdf*.

[25] Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development*, Englewood Cliffs, N.J.: Prentice-Hall, 1984.

[26] Sharp, J.E., "Teaching Teamwork Communication with Kolb Learning Style Theory," *Proceedings, 2001 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[27] Bernold, L.E., Bingham, W.L., McDonald, P.H., and Attia, T.M., "Impact of Holistic and Learning-Oriented Teaching on Academic Success," *Journal of Engineering Education*, Vol. 89, No. 2, 2000, pp. 191–199.

[28] Harb, J.N., Durrant, S.O., and Terry, R.E., "Use of the Kolb Learning Cycle and the 4MAT System in Engineering Education," *Journal of Engineering Education*, Vol. 82, No. 2, 1993, pp. 70–77.

[29] Spurlin, J.E., Bernold, L.E., Crossland, C.L., and Anson, C.M., "Understanding How Freshman Engineering Students Think They Learn," *Proceedings, 2003 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[30] Sharp, J.E., Harb, J.N., and Terry, R.E., "Combining Kolb Learning Styles and Writing to Learn in Engineering Classes," *Journal of Engineering Education*, Vol. 86, No. 2, 1997, pp. 93–101.

[31] Sharp, J.E., "Learning Styles and Technical Communication: Improving Communication and Teamwork Skills," *Proceedings, 1998 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[32] Felder, R.M., "Reaching the Second Tier: Learning and Teaching Styles in College Science Education," *Journal of College Science Teaching*, Vol. 23, No. 5, 1993, pp. 286–290. Online at *www.ncsu.edu/felder-public/Papers/Secondtier.html*.

[33] Rosati, P.A., and Felder, R.M., "Engineering Student Responses to an Index of Learning Styles," *Proceedings, 1995 ASEE Conference Exposition*, Washington, D.C.: American Society for Engineering Education.

[34] Rosati, P.A., "Comparisons of Learning Preferences in an Engineering Program," *Proceedings, 1996 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[35] Rosati, P.A., "Specific Differences and Similarities in the Learning Preferences of Engineering Students," *Proceedings, 1999 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[36] Zywno, M.S., and Waalen, J.K., "The Effect of Hypermedia Instruction on Achievement and Attitudes of Students with Different Learning Styles," *Proceedings, 2001 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[37] Livesay, G.A., Dee, K.C., Nauman, E.A., and Hites, Jr., L.S., "Engineering Student Learning Styles: A Statistical Analysis Using Felder's *Index of Learning Styles*," Presented at the *2002 ASEE Conference and Exposition*, Montreal, Quebec, June 2002.

[38] Zywno, M.S., "Instructional Technology, Learning Styles, and Academic Achievement," *Proceedings, 2002 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[39] Dee, K.C., Livesay, G.A., and Nauman, E.A., "Learning Styles of First- and Second-Year Engineering Students," *Proceedings, 2003 ASEE/WFEO International Colloquium*, Washington, D.C.: American Society for Engineering Education.

[40] Sharp, J.E., "A Resource for Teaching a Learning Styles/Teamwork Module with the Soloman-Felder Index of Learning Styles," *Proceedings, 2003 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[41] Herrmann, N., *The Creative Brain*, Lake Lure, N.C.: Brain Books, 1990.

[42] Lumsdaine, E., and Voitle, J., "Introducing Creativity and Design into Traditional Engineering Design Courses," *Proceedings, 1993 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

43. Lumsdaine, M., and Lumsdaine, E., "Thinking Preferences of Engineering Students: Implications for Curriculum Restructuring," *Journal of Engineering Education*, Vol. 84, No. 2, 1995, pp. 193–204.

[44] Dunn, R., Beaudry, J.S., and Klavas, A., "Survey of Research on Learning Styles," *Educational Leadership*, Vol. 46, No. 6, 1989, pp. 50–58.

[45] Dunn, R., "Understanding the Dunn and Dunn Learning Styles Model and the Need for Individual Diagnosis and Prescription," *Reading, Writing, and Learning Disabilities*, Vol. 6, 1990, pp. 223–247.

[46] Hein, T.L., and Budny, D.D., "Teaching to Students' Learning Styles: Approaches That Work," *Proceedings, 1999 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[47] Felder, R.M., "Meet Your Students. 1. Stan and Nathan," *Chemical Engineering Education*, Vol. 23, No. 2, 1989, pp. 68–69. Online at *www.ncsu.edu/felder-public/Columns/Stannathan.html*.

[48] Felder, R.M., "Meet Your Students. 2. Susan and Glenda," *Chemical Engineering Education*, Vol. 24, No. 1, 1990, pp. 7–8. Online at *www.ncsu.edu/felder-public/Columns/Susanglenda.html*.

[49] Felder, R.M., and Soloman, B.A., *Index of Learning Styles*, *http://www.ncsu.edu/felder-public/ILSpage.html*.

[50] Felder, R.M., and Spurlin, J., "Applications, Reliability, and Validity of the Index of Learning Styles," *International Journal of Engineering Education*, in press.

[51] Constant, K.P., "Using Multimedia Techniques to Address Diverse Learning Styles in Materials Education," *Journal of Materials Education*, Vol. 19, 1997, pp. 1–8.

[52] Paterson, K.G., "Student Perceptions of Internet-Based Learning Tools in Environmental Engineering Education," *Journal of Engineering Education*, Vol. 88, No. 3, 1999, pp. 295–304.

[53] De Vita, G., "Learning Styles, Culture and Inclusive Instruction in the Multicultural Classroom: A Business and Management Perspective," *Innovations in Education and Teaching International*, Vol. 38, No. 2, 2001, pp. 165–174.

[54] Zywno, M.S., "A Contribution of Validation of Score Meaning for Felder-Soloman's *Index of Learning Styles*," *Proceedings, 2003 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[55] Lopes, W.M.G., *ILS—Inventário de Estilos de Aprendizagem de Felder-Soloman: Investigação de sua Validade em Estudantes Universitários de Belo Horizonte*, Masters Thesis, Universidade Federal de Santa Caterina,Brazil, 2002.

[56] Seery, N., Gaughran, W.F., and Waldmann, T., "Multi-Modal Learning in Engineering Education," *Proceedings, 2003 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[57] Montgomery, S., "Addressing Diverse Student Learning Styles through the Use of Multimedia," *Proceedings, 1995 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[58] Buxeda, R., and Moore, D.A., "Using Learning Styles Data to Design a Microbiology Course," *Journal of College Science Teaching*, Vol. 29, 1999, pp. 159–164.

[59] Buxeda, R., Jimenez, L., and Morell, L., "Transforming an Engineering Course to Enhance Student Learning," *Proceedings. 2001 International Conference on Engineering Education*, Arlington, Va.: International Network for Engineering Education and Research.

[60] Kuri, N.P., and Truzzi, O.M.S., "Learning Styles of Freshmen Engineering Students," *Proceedings, 2002 International Conference on Engineering Education*, Arlington, Va.: International Network for Engineering Education and Research.

[61] Smith, N.G., Bridge, J., and Clarke, E., "An Evaluation of Students' Performance Based on Their Preferred Learning Styles," in Pudlowski, Z.L., ed., *Proceedings, 3rd Annual Conference of the UNESCO International Centre for Engineering Education*, Melbourne, Australia: UICEE, 2002.

[62] Hayes, J., and Allinson, C.W., "Matching Learning Style and Instructional Strategy: An Application of the Person-Environment Interaction Paradigm," *Perceptual and Motor Skills*, Vol. 76, 1993, pp. 63–79.

[63] Hayes, J., and Allinson, C.W., "The Implications of Learning Styles for Training and Development: A Discussion of the Matching Hypothesis," *British Journal of Management*, Vol. 7, 1996, pp. 63–73.

[64] Marton, F., and Säljö, R., "Approaches to Learning," in Marton et al. [92].

[65] Ramsden, P., *The Lancaster Approaches to Studying and Course Perceptions Questionnaire: Lecturer's Handbook*, Oxford: Educational Methods Unit, Oxford Polytechnic, 1983.

[66] Woods, D.R., Hrymak, A.N., and Wright, H.M., "Approaches to Learning and Learning Environments in Problem-based vs. Lecture-based Learning," *Proceedings, 2000 ASEE Conference and Exposition,* Washington, D.C.: American Society for Engineering Education.

[67] Biggs, J.B., *Study Process Questionnaire*, Australia: University of Newcastle, 1979.

[68] Bertrand, D., and Knapper, C.K., "Contextual Influences on Students' Approaches to Learning in Three Academic Departments," Unpublished honors thesis, Psychology Department, University of Waterloo, Waterloo, ON, Canada, 1991 (cited by Woods et al., [66]).

[69] Prosser, M., and Trigwell, K., *Understanding Learning and Teaching*, Buckingham: The Society for Research into Higher Education and Open University Press, 1999.

[70] Prosser, M., and Millar, R., "The 'How' and 'Why' of Learning Physics," *European Journal of Psychology of Education*, Vol. 4, 1989, pp. 513–528.

[71] Meyer, J.H.F., Parsons, P., and Dunne, T.T., "Individual Study Orchestrations and their Association with Learning Outcome," *Higher Education*, Vol. 20, 1990, pp. 67–89.

[72] Dochy, F., Segers, M., Van den Bossche, P., and Gijbels, D., "Effects of Problem-Based Learning: A Meta-Analysis," *Learning and Instruction*, Vol. 13, 2003, pp. 533–568.

[73] Duch, B.J., Groh, S.E., and Allen, D.E., eds., *The Power of Problem-Based Learning*, Sterling, Va.: Stylus, 2001.

[74] de Graaf, E. and Kolmos, A., "Characteristics of Problem-Based Learning," *International Journal of Engineering Education*, Vol. 19, No. 5, 2003, pp. 657–662.

[75] Kolmos, A., Fink, F.K., and Krogh, L., eds., *The Aalborg PBL Model: Progress, Diversity, and Challenges*, Aalborg, Denmark: Aalborg University Press, 2004.

[76] McMaster University Problem-Based Learning Web Site, *http://www.chemeng.mcmaster.ca/pbl/ PBL.HTM*.

[77] University of Delaware Problem-Based Learning Web Site, *http://www.udel.edu/pbl*.

[78] Gronlund, N.E., *How to Write and Use Instructional Objectives*, 5th ed., New York, N.Y.: Macmillan, 1994.

[79] Mager, R.F., *Preparing Instructional Objectives*, 3rd ed., Atlanta, Ga.: Center for Effective Performance, 1997.

[80] Felder, R.M., and Brent, R., "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," *Journal of Engineering Education*, Vol. 92, No. 1, 2003, pp. 7–25. Online at *http://www.ncsu.edu/felder-public/Papers/ABET_Paper_(JEE).pdf*.

[81] Felder, R.M., and Brent, R., "Learning by Doing," *Chemical Engineering Education*, Vol. 37, No. 4, 2003, pp. 282–283. Online at *http://www.ncsu.edu/felder-public/Columns/Active.pdf*.

[82] Prince, M., "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, Vol. 93, No. 3, 2004, pp. 223–231.

[83] Johnson, D.W., Johnson, R.T., and Smith, K.A., *Active Learning: Cooperation in the College Classroom,* 2nd ed., Edina. Minn.: Interaction Book Co, 1998.

[84] Smith, K.A., Johnson, D.W., Johnson, R.W., and Sheppard, S.D., "Pedagogies of Engagement: Classroom-Based Practices," *Journal of Engineering Education*, Vol. 94, No. 1, 2005, pp. ***–***.

[85] Trigwell, K., Prosser, M., Ramsden, P., and Martin, E., "Improving Student Learning through a Focus on the Teaching Context," in Gibbs, G., ed., *Improving Student Learning*, Oxford: Oxford Centre for Staff Development, 1998.

[86] Trigwell, K., Prosser, M., and Waterhouse, F., "Relations between Teachers' Approaches to Teaching and Students' Approaches to Learning," *Higher Education*, Vol. 37, 1999, pp. 57–70.

[87] Chickering, A.W., and Gamson, Z.F., *Applying the Seven Principles for Good Practice in Undergraduate Education*, New Directions for Teaching and Learning, No. 47, San Francisco, Cal.: Jossey-Bass, 1991.

[88] Eble, K.E., *The Craft of Teaching*, 2nd ed., San Francisco, Cal.: Jossey-Bass, 1988.

[89] Felder, R.M., "Designing Tests to Maximize Learning," *Journal of Professional Issues in Engineering Education and Practice*, Vol. 128, No. 1, 2002, pp. 1–3. Online at *http://www.ncsu.edu/felder-public/Papers/TestingTips.htm*.

[90] Lowman, J., *Mastering the Techniques of Teaching*, 2nd ed., San Francisco, Cal.: Jossey-Bass, 1995.

[91] Wankat, P., *The Effective, Efficient Professor: Teaching, Scholarship, and Service*, Boston, Mass.: Allyn and Bacon, 2002.

[92] Marton, F., Hounsell, D., and Entwistle, N., eds., *The Experience of Learning*, 2nd ed., Edinburgh: Scottish Academic Press, 1997.

[93] Kroll, B.M., *Teaching Hearts and Minds: College Students Reflect on the Vietnam War in Literature*, Carbondale, Ill.: Southern Illinois University Press, 1992.

[94] Felder, R.M., and Brent, R., "The Intellectual Development of Science and Engineering Students. 1. Models and Challenges," *Journal of Engineering Education*, Vol. 93, No. 4, 2004, pp. 269–277.

[95] Felder, R.M., and Brent, R., "The Intellectual Development of Science and Engineering Students. 2. Teaching to Promote Growth," *Journal of Engineering Education*, Vol. 93, No. 4, 2004, pp. 279–291.

[96] Perry, W.G., *Forms of Intellectual and Ethical Development in the College Years: A Scheme*, San Francisco, Cal.: Jossey-Bass, 1988. (An updated reprint of the original 1970 work.)

[97] Love, P.G., and Guthrie, V.L., *Understanding and Applying Intellectual Development Theory*, New Directions for Student Services, No. 88, San Francisco, Cal.: Jossey-Bass, 1999.

[98] Culver, R.S., and Hackos, J.T., "Perry's Model of Intellectual Development," *Engineering Education*, Vol. 72, 1982, pp. 221–226.

[99] Fitch, P., and Culver, R.S., "Educational Activities to Stimulate Intellectual Development in Perry's Scheme," *Proceedings, 1984 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[100] Pavelich, M.J., and Fitch, P., "Measuring Students' Development Using the Perry Model," *Proceedings, 1988 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[101] Pavelich, M.J., "Helping Students Develop Higher-Level Thinking: Use of the Perry Model," *Proceedings, 1996 Frontiers in Education Conference*, Washington, D.C.: ASEE/IEEE.

[102] Pavelich, M.J., and Moore, W.S., "Measuring the Effect of Experiential Education Using the Perry Model," *Journal of Engineering Education*, Vol. 85, No. 4, 1996, pp. 287–292.

[103] Felder, R.M., "Meet Your Students. 7. Dave, Martha, and Roberto," *Chemical Engineering Education*, Vol. 31, No. 2, 1997, pp. 106–107. Online at *http://www.ncsu.edu/felder-public/Columns/ Perry.html*.

[104] Pavelich, M.J., Miller, R.L., and Olds, B.M., "Software for Measuring the Intellectual Development of Students: Advantages and Limitations," *Proceedings, 2002 ASEE Conference and Exposition*, Washington, D.C.: American Society for Engineering Education.

[105] Marra, R., and Palmer, B., "Encouraging Intellectual Growth: Senior College Student Profiles," *Journal of Adult Development*, Vol. 11, No. 2, 2004, pp. 111–122.

[106] Wise, J., Lee, S.H., Litzinger, T.A., Marra, R.M., and Palmer, B., "A Report on a Four-Year Longitudinal Study of Intellectual Development of Engineering Undergraduates," *Journal of Adult Development*, Vol. 11, No. 2, 2004, pp. 103–110.

[107] King, P.M., and Kitchener, K.S., *Developing Reflective Judgment: Understanding and Promoting Intellectual Growth and Critical Thinking in Adolescents and Adults*, San Francisco, Cal.: Jossey Bass, 1994.

[108] King, P.M., and Kitchener, K.S., "The Reflective Judgment Model: Twenty Years of Research on Epistemic Cognition," in Hofer, B.K. and Pintrich, P.R., eds., *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing*, Mahwah, N.J.: Lawrence Erlbaum Associates, 2001.

[109] Belenky, M.F., Clinchy, B.M., Goldberger, N.R., and Tarule, J.M., *Women's Ways of Knowing: The Development of Self, Voice, and Mind*, New York, N.Y.: Basic Books, 1986 (reissued 1997).

[110] Baxter Magolda, M.B., *Knowing and Reasoning in College*. San Francisco, Cal.: Jossey-Bass, 1992.

[111] Moore, W.S., *The Measure of Intellectual Development: An Instrument Manual*, Olympia, Wash.: Center for the Study of Intellectual Development, 1988.

[112] Baxter Magolda, M.B., and Porterfield, W.D., *Assessing Intellectual Development: The Link between Theory and Practice*, Alexandria, Va.: American College Personnel Association, 1988.

[113] Baxter Magolda, M.B., "A Constructivist Revision of the Measure of Epistemological Reflection," *Journal of College Student Development*, Vol. 42, No. 6, 2001, pp. 520–534.

[114] Moore, W.S., "The Learning Environment Preferences: Exploring the Construct Validity of an Objective Measure of the Perry Scheme," *Journal of College Student Development*, Vol. 30, 1989, pp. 504–514.

[115] Wood, P.K., King, P.M., Kitchener, K.S., and Lynch, C.L., *Technical Manual for the Reflective Thinking Appraisal*, Columbia, Mo.: University of Missouri, 1994.

[116] Vygotsky, L.S., *Mind in Society: The Development of Higher Psychological Processes*, Cambridge, Mass: Harvard University Press, 1978.

[117] Woods, D.R., et al., "Developing Problem-Solving Skills: The McMaster Problem Solving Program," *Journal of Engineering Education*, Vol. 86, No. 2, 1997, pp. 75–92.

[118] Marra, R.M., Palmer, B., and Litzinger, T.A., "The Effects of a First-Year Design Course on Student Intellectual Development as Measured by the Perry Scheme," *Journal of Engineering Education*, Vol. 89, No. 1, 2000, pp. 39–45.

[119] Hake, R.R., "Interactive Engagement vs. Traditional Methods: A Six-thousand Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics*, Vol. 66, 1998, pp. 64–74.

[120] Springer, L., Stanne, M.E., and Donovan, S., *Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis*, 1998, *http://www.wcer.wisc.edu/nise/CL1/CL/resource/R2.htm*.

[121] Johnson, D.W., Johnson, R.T., and Stanne, M.B., "Cooperative Learning Methods: A Meta-Analysis," May 2000, *http://www.co-operation.org/pages/cl-methods.html*.

[122] Terenzini, P.T., Cabrera, A.F., Colbeck, C.L., Parente, J.M., and Bjorklund, S.A., "Collaborative Learning vs. Lecture/Discussion: Students' Reported Learning Gains," *Journal of Engineering Education*, Vol. 90, No. 1, 2001, pp. 123–130.

[123] Fagen, A.P., Crouch, C.H., and Mazur, E., "Peer Instruction: Results from a Range of Classrooms," *The Physics Teacher*, Vol. 40, 2002, pp. 206–209. Online at *http://mazur-www.harvard.edu/publications/Pub_286.pdf*.

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