THE INTELLECTUAL DEVELOPMENT OF SCIENCE AND ENGINEERING STUDENTS PART 1. MODELS AND CHALLENGES*

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ABSTRACT

As college students experience the challenges of their classes and extracurricular activities, most undergo a developmental progression in which they gradually relinquish their belief in the certainty of knowledge and the omniscience of authorities and take increasing responsibility for their own learning. At a high developmental level (which few reach before graduation), they recognize that all knowledge is contextual, gather and interpret evidence to support their judgments from a wide range of sources, and willingly reconsider those judgments in the light of new evidence. This paper reviews several models of intellectual development, discusses their applicability to science and engineering education, and defines the difficulties that confront instructors seeking to promote the development of their students. A subsequent paper formulates an instructional model for promoting development that addresses those difficulties.

Keywords: Intellectual development, Baxter Magolda's model, Perry's model

I. INTRODUCTION

Kroll [1] describes intellectual growth as the progression from ignorant certainty to intelligent confusion. Many entering college students are firmly rooted in ignorant certainty. Their beliefs about the world are clear, absolute, and based entirely on what they have been told by others—parents, teachers, and influential peers. They have never subjected these beliefs to critical questioning or looked for evidence to test their validity. They view all knowledge as either certain or unknowable, with scientific knowledge residing squarely in the domain of certainty. In their minds, the role of teachers is to know The Truth and to tell it to them and their role as students is to absorb it and repeat it back on assignments and tests.

These students' view of science (and of every other domain of human knowledge) is quite wrong. Nothing can be considered certain. All observations and data, whether obtained through the human senses or with sophisticated instruments, involve uncertainty, and all attempts to explain, correlate, or model the observations and data must be considered hypothetical, approximate, contextually limited, and subject to subsequent modification or replacement.

As students progress through college, their beliefs are challenged by teachers, classmates, and life experiences, and unless they firmly close their minds to those challenges (which some do), the rigidity and naiveté of their beliefs diminish and their intellectual growth proceeds. They become aware that not all knowledge is certain and they begin to make judgments on the basis of evidence, although their selection and interpretation of evidence tends to be superficial. As they progress still farther, they may attain Kroll's state of intelligent confusion, recognizing that all knowledge is contextual and becoming relatively sophisticated in their use of evidence to make judgments. In other words, they may start to think like scientists and engineers. The goal of science and engineering education should be to bring students to this point.

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A prerequisite to helping students attain the intellectual maturity they will need to function effectively as professionals is to understand the stages of their progression from ignorant certainty to intelligent confusion—what their attributes are at each stage and what kind of stimulation might facilitate their movement to higher stages. Models of college students' intellectual development can contribute to this understanding. This paper reviews several prominent models and explores their implications for science and engineering education. A subsequent paper [2] outlines an instructional approach designed to meet the learning needs of students over the full spectrum of developmental levels.

II. MODELS OF INTELLECTUAL DEVELOPMENT

A. Perry's Model

In the 1950s, William Perry—then director of the Bureau of Student Counseling at Harvard—carried out a longitudinal study of liberal arts students at Harvard and Radcliffe to determine how they responded to the various intellectual and moral challenges they encountered in their college experience. By examining open-content interview transcripts and complete four-year college records, he and his colleagues observed that intellectual growth appears to take place in distinct stages, characterized by different views of how truth should be determined. He formulated an empirical model based on his observations and then tested it with better controls and larger samples, arriving finally at a widely cited nine-point scale. Reviews of Perry's model are provided by Perry [3] and Love and Guthrie [4], and applications to engineering education are described in a number of studies [5–11].

According to Perry's model, individuals proceed from blind acceptance of authority at Levels 1 and 2 (a dualistic view of the world, in which all intellectual and moral questions have unique correct answers, authorities know what those answers are, and the students' task is to accept the authorities' answers without question and to repeat those answers on tests) through gradual acceptance of multiplicity of views and concomitant withdrawal from reliance on the word of authorities at Levels 3–4, relativism at Level 5 (characterized by a belief there are no absolute answers nor reliable authorities—all knowledge and values are seen as contingent and contextual), awareness of the necessity for commitment in the face of uncertainty at Level 6, and finally the undertaking of such commitments and coming to terms with their implications at Levels 7–9.

Perry found that the students he studied entered college at a number of levels, including Level 1. He also found that most of the students he studied reached Level 6 by the time they graduated, with a few even reaching Level 9. Subsequent studies of intellectual development on the Perry scale have reached less gratifying conclusions, however. In particular, most entering students in science and engineering are found to be in the range 2.5–3.5 and fewer than one-third make it as far as Level 5 [8,9]. Studies by Jehng et al. [12] and Paulsen and Wells [13] show that students in engineering and science are more likely than students in social sciences and humanities to believe in the certainty of knowledge and in authority as its source.

Those beliefs are of course mistaken. Real science and engineering (as opposed to much of what is taught in pre-college and college curricula) are all about testing accepted knowledge and challenging authority, accepting the inevitability of uncertainty and ambiguity, and eventually committing to theories and models on the basis of the best available evidence while acknowledging that the theories and models will eventually have to be revised or rejected as better evidence emerges. It may be that the nature of the liberal arts curriculum at Harvard, which involved heavy doses of philosophy and literary interpretation, pushed students in the direction of questioning authority, accepting multiplicity and relativism, and eventually committing in the face of uncertainty—hence, the high levels attained by Perry's subjects. Unfortunately, despite noteworthy progress in science and engineering curriculum reform in recent years, many courses are still taught in what Wankat [14] terms a "dualistic mode," emphasizing facts and well-established principles and procedures and not introducing multiplicity until case study, research, or (in engineering) design experiences are provided in the senior year. Wise *et al.* [9] assessed Perry levels of engineering students in their second, fifth, and eighth semester of college and found that most of their observed growth took place between the second and third assessments, a result consistent with Wankat's observation.

B. Women's Ways of Knowing

The Perry model has been challenged on the grounds that its validation was based almost entirely on interviews with men and fails to account for gender differences in developmental patterns. In *Women's Ways of Knowing*, Belenky *et al.* [15] report on a study in which 135 women were interviewed on their life experiences. Transcripts of the interviews were systematically examined to identify five different perspectives on knowing displayed by the subjects. Most of the perspectives had counterparts in the Perry model but differed in certain ways that the authors attributed to gender differences in patterns of intellectual development.

The levels of the Belenky model are:

1. *Silence*, characterized by isolation, a sense of helplessness, and complete surrender of power to authorities. Few women participating in Belenky's study and none with college experience fell into this category.
2. *Received knowing*, characterized by a belief that all ideas and answers are right or wrong, the authorities know which is which, and the sole job of the student is to memorize and repeat whatever the authorities say. The parallel to Perry's dualism is clear, but while Perry's dualists are often outspoken and possibly confrontational with peers about their ideas and attempt to align themselves with authority figures, received knowers are more concerned with getting along with peers and tend to feel alienated from authorities.
3. *Subjective knowing*, which rejects authorities and peers as reliable sources of truth and analytical reasoning as a basis for judgment, relying instead on personal knowledge, experience, and intuition (gut feelings, inner voices).
4. *Procedural knowing*, which recognizes that intuition can be wrong and augments or replaces it with observation, analysis, and other people's expertise, often rigidly (and sometimes inappropriately) adhering to prescribed analytical methods regardless of the issue being addressed. Two gender-related patterns of this category—separate knowing and connected knowing—are described below, the first of which resembles the later stages of Perry's multiplicity (Level 4).
5. *Constructed knowledge*, which acknowledges both intuition and the ideas of authorities and peers as valid sources of knowledge and makes increasingly sophisticated use of both objective logic and subjective feelings when making judgments. The notion of absolute truth is rejected at this level: the individual recognizes that all knowledge is contextual and the knower plays a vital role in constructing it. This pattern strongly resembles Level 5 of Perry's model.

Drawing on concepts defined by Gilligan [16], Belenky *et al.* [15] proposed two different patterns for the procedural knowledge level: separate knowing and connected knowing. Separate knowers work hard to eliminate subjective feelings from their decision-making process. They rely on critical thinking to arrive at truth, subjecting all ideas and beliefs—including their own—to intense scrutiny and doubt, although women who exhibit this pattern are less likely than similarly oriented men to do their challenging in confrontational public forums. Connected knowers take the opposite tack and treat personal experience as the most reliable source of knowledge. Unlike subjective knowers, however, they believe that other people's experience is at least as valuable as theirs and they go to great lengths to understand and empathize with others, honoring their points of view and ways of thinking and avoiding negative judgments as long as they can. Thus, while doubt is the first response of separate knowers, it is the last resort of connected knowers.

C. The King-Kitchener Model of Reflective Judgment

In the 1980s, Patricia King and Karen Kitchener developed and validated a widely used model of how students develop *reflective judgment*—that is, how they learn to evaluate knowledge claims and to justify their beliefs about arguable issues [17–19]. The model is based on John Dewey's work on reflective thinking, and its levels closely parallel the first six levels of Perry's model. Perry's dualism and multiplicity subordinate (Levels 1–3) correspond to King and Kitchener's 3-level *prereflective thinking*. Students at the first two levels believe in the certainty of knowledge and make judgments based exclusively on direct observation and the word of authorities. Students at the third level accept the existence of uncertainty but believe that it is only temporary, and they do not use evidence to make judgments about uncertain issues. Perry's multiplicity (Level 4) is King and Kitchener's 2-level *quasi-reflective thinking*. Quasi-reflective thinkers use evidence to make judgments about uncertain issues, but they do so sporadically and superficially. Students at the lower level believe that all judgments are idiosyncratic, with evidence being interpreted according to the judger's beliefs, and so the quality of the judgments cannot themselves be judged. Students at the higher level of quasi-reflective thinking are moving toward relativism, accepting that knowledge is contextual, becoming more sophisticated in the use of evidence to justify conclusions, and acknowledging that how well the rules of inquiry for a given context are followed is a valid basis for grading. Finally, Perry's relativism (Levels 5 and 6 and possibly 7) is analogous to King and Kitchener's 2-level *reflective thinking*. Reflective thinkers accept the inevitably of uncertainty in decision making but they are not immobilized by it. They make judgments and decisions on the basis of a careful weighing of all available evidence, the practicality of the solution, and the pragmatic need for action.

An extensive research base supports the constructs of the King-Kitchener model and chronicles the progression in levels of college students from freshman to senior years [14,15]. The data closely match the previously cited studies of engineering students based on the Perry model. On average, freshmen enter college at the level of prereflective thinking (dualism), basing their judgments on unsubstantiated beliefs and the pronouncements of authorities, and leave at the quasi-reflective thinking level (multiplicity), beginning to seek and use evidence to support their judgments. Very few graduates reach the level of reflective thinking (contextual relativism), however: among students studied using the King-Kitchener model, only advanced doctoral students were consistently found to reason reflectively.

D. Baxter Magolda's Model of Epistemological Development

A multi-level model that reconciles and extends the models just discussed was formulated by Marcia Baxter Magolda [20,21], who interviewed 101 students (51 women and 50 men) and observed two distinct behavior patterns at several of the levels. One of the patterns characterized more men than women and involved behaviors that resembled those of the Perry model, and the other characterized more women than men and involved behaviors like those in Belenky's model. Table 1 briefly defines the levels of Baxter Magolda's model and gives correspondences between that model and the other three mentioned above. The paragraphs that follow discuss Baxter Magolda's levels in greater detail.

Table 1
Models of Intellectual Development

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 knowledge is contextual and individually constructed. 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.

1. Absolute Knowing—Mastery and Receiving Patterns.

Absolute knowers believe that all knowledge that matters is certain, all questions that matter have one correct answer, and authorities have the knowledge and the answers. Lecture is the only legitimate form of instruction, and a good teacher is one who provides clear and unambiguous statements of the things the students are expected to know and gives repeated practice in the required problem-solving procedures. The student's task is to memorize the knowledge, practice the procedures, and repeat both on examinations. Instructors have no right to ask students to answer questions or solve problems that deviate in any way from the material covered in the lectures. If instructors occasionally seem uncertain, it is either because they lack competence or they are simply playing a game designed to force the students to find the answers for themselves (a game students at this level hate). These students exhibit the lowest of three epistemological orientations to science and engineering proposed by Palmer and Marra [11], viewing science as a collection of known facts. They have trouble understanding the instructor's use of evidence as the basis of judgments or decisions, and they are essentially incapable of gathering and using evidence as a basis for their own judgments.

Students in the *mastery pattern* of absolute knowing feel free to ask questions in class to make sure they have the information correct and also to challenge grading based on anything but how well they replicate information presented in the lectures. They detest open-ended questions and regard active learning and other student-centered teaching methods as time-wasting digressions from the lectures. Peers may be useful for mutual quizzing and debating but not as legitimate sources of information. This pattern characterizes men more often than women.

Unlike their relatively argumentative counterparts in the mastery pattern, students in the *receiving pattern* of absolute knowing function in a relatively passive way, taking in and recording information and interacting minimally with instructors. They also do not recognize peers as legitimate sources of information but instead view them as sources of mutual sharing and support, and so they are relatively receptive to team-based activities. Women are more likely than men to fall into this category.

2. Transitional Knowing—Impersonal and Interpersonal Patterns.

To students at the level of transitional knowing, authorities have lost their omniscience. Knowledge may be certain or—at least temporarily—uncertain, and when judgments regarding uncertain knowledge must be made, the transitional knowers see themselves as having the primary responsibility for making them, either by following a prescribed instructor-formulated process (impersonal pattern) or by following their feelings (interpersonal pattern). These students have begun to exhibit Palmer and Marra's second orientation, viewing science as a set of theories and facts with exceptions [11].

To students in the *impersonal pattern*, the instructor's job moves from simple transmission of knowledge to helping students learn how to determine it for themselves, and they are still inclined to turn to authorities for final resolution of questions. They may accept the validity of using logical reasoning as the basis for their judgments but are apt to accept unquestioned beliefs and biases as valid evidence. They believe that if they work hard and follow the right procedure on assignments and exams they should get full credit, regardless of the clarity of their reasoning and the quality of their evidence. They are scornful of the subjectivity of the humanities and social sciences and take comfort in what they view as the purely objective nature of science and engineering, and they are bewildered or irritated if this view is contradicted by their instructors. Peers are valued as debating partners for sharpening ideas and they may be acknowledged as legitimate sources of information if they are strong academically, but establishing rapport with them is not the goal that it is in the interpersonal pattern. Men are more likely than women to fall into this pattern.

Students in the *interpersonal pattern* like to collect lots of ideas from both instructors and peers when issues are uncertain, but they base their final decisions on personal judgment and what makes the most sense to them. They value instructors who create rapport with students, take individual differences into account in instruction and testing, and encourage self-expression and involvement with peers. They distrust logic, analysis, and abstract theories, and they often display a sharp reaction to and rejection of formerly revered authorities. Many students in this position turn away from science—which they view as cold, inhuman, dogmatic, manipulative, and the enemy of the intuitive subjective knowing that they believe in—and switch to the arts and humanities. This pattern characterizes women more often than men.

3. Independent Knowing—Individual and Interindividual Patterns.

The uncertainty of some knowledge is accepted as a fact of life by independent knowers. They have learned to take responsibility for their own learning, applying objective procedures for obtaining and communicating knowledge rather than simply trusting the word of authorities or their own gut feelings. The role of instructors is to encourage and provide context for independent thought and to promote exchanges of opinions. Learning procedures become important for their own sake, as though it doesn't matter what conclusion one reaches as long as it is reached independently using accepted procedures. These students are likely to resent being graded negatively for the quality of their reasoning in what they regard as matters of opinion (a broad category that includes all moral and ethical issues). They tend to follow narrowly defined channels in their inquiries, even when what is really called for is a departure from established forms. They consider both peers and instructors as legitimate sources of information, but they feel free to ignore both in matters that are even remotely subjective. They remain within Palmer and Marra's second orientation to science (theories and facts with exceptions).

Students in the *individual pattern* of independent knowing rely on objective logic, critical thinking, and adversarial challenging of their own and others' positions to establish truth and make moral judgments. They often start out by adopting that stance because they think that's what their teachers want them to do, but eventually they may internalize it. Their highest value is independent thought. Listening carefully to other opinions is considered important but only as a means of clarifying their own viewpoints. This pattern characterizes men more often than women.

Students in the *interindividual pattern* use caring and empathy as the bases of their efforts to understand and judge. When someone expresses an idea with which they take issue, rather than challenging it as those in the individual pattern would, they attempt to understand the factors that led the speaker to reason that way, see things through his or her eyes, and refrain from premature judgment. Listening to others and learning from them are viewed as equally important as expressing their own views, with clarification emerging from the mutual interactions. Peers and instructors are viewed as equally credible partners in such exchanges, and establishing relationships with both is considered an important part of the learning process. Since the individual pattern is compatible with the perspective of many science and engineering instructors, students in the interindividual pattern tend to have a harder time adapting to academic demands and are more likely to switch to other curricula, even if they are doing well academically. This pattern characterizes women more often than men.

People familiar with the Myers-Briggs Type Indicator might observe that the descriptions of the male-dominant patterns (mastery, impersonal, individual/separate) include many attributes of the MBTI thinker, and the female-dominant patterns (receiving, interpersonal, interindividual/connected) evoke images of the MBTI feeler. Ullman-Petrash [22] hypothesized such connections. She subjected 21 female university students to interviews of the type used by Belenky *et al.* [15] to assess preferences for separate or connected ways of knowing, and she also had the subjects complete the MBTI. Of her 21 subjects, 16 confirmed the hypothesis (8 thinkers/separate knowers and 8 feelers/connected knowers) and 5 negated it (2 thinkers/connected knowers and 3 feelers/separate knowers). The probability of 16 or more matches occurring was less than or equal to 0.02, supporting both the hypothesized relationships and the validity of both sets of constructs. Instruction designed to address the needs of both thinkers and feelers should therefore also be appropriate for both men and women at Baxter Magolda's four levels and Belenky's Procedural Knowledge level.

4. Contextual Knowing—The Patterns Converge.

Contextual knowers reject once and for all the notion that absolute truth exists. They experience themselves as constructors of their own knowledge, and their strategies for carrying out the construction integrate elements from the prior levels—objective analysis and intuition, their own thoughts, and ideas of others whose expertise they acknowledge. They move away from the idea that all opinions are equally valid as long as the right method is used to arrive at them, and they start to recognize the need to base judgments on the best available evidence within the given context, even in the face of uncertainty and ambiguity. They value real dialogue when important issues are discussed (unlike individuals at lower levels, who use dialogue mainly to advance their own ideas and don't pay much attention to what others are saying), and rely less on abstract principles than on contextual considerations when making decisions.

Their contextual mindset influences how these individuals view science. At earlier levels, science is mistakenly seen as a collection of objective facts that are either known and understood now (Palmer and Marra's first orientation) or will be known and understood eventually if the correct investigation procedures are followed (Palmer and Marra's second orientation). Contextual knowers exhibit Palmer and Marra's third and highest orientation [11], correctly viewing science as a collection of approximate models of reality that the scientist must play a part in constructing. The models are only as good as the data used to validate them and are liable to be replaced at any time by alternative models that provide a better fit to available data. These students' skepticism and willingness to challenge what is currently known and to question the assumptions underlying all assertions, their tolerance of ambiguity (which deters them from rushing to accept the first plausible explanation that arises), their inclination to use both logic and intuition in their investigations, and their unwillingness to transfer judgments made in one context to another context without critical evaluation, could almost stand as a definition of what first-rate scientists and engineers do.

E. Social and Emotional Influences on Intellectual Development

Early studies of intellectual development characterized the developmental positions through which individuals progress but did not delve deeply into the factors outside of classroom experiences that catalyze the progression. More recent studies have demonstrated strong influences on intellectual development of interpersonal interactions among students and between students and instructors, cultural predispositions, and students' emotional states [23–25].

All of the models we have discussed are based on the principle that ways and patterns of knowing are socially constructed, which places interpersonal interactions at their heart. The influence of interactions on development was observed by Perry, who noticed that dualistic students were often prodded to move to multiplicity by the diversity of opinions they encountered in their residence halls and that debating ideas with both peers and professors led many multiplists to recognize the need to provide better evidence for their arguments, a critical step in the transition to relativism. Belenky *et al.* [15] and Baxter Magolda [20] note the vital importance of social relationships and interactions to individuals exhibiting the female-predominant patterns at all levels, adding that connectedness and positive social interactions benefit men (and presumably, women in the male-predominant patterns) as well, and the authors also note the potentially inhibiting effect on growth of peer interactions that reinforce the types of thinking characteristic of students' current levels.

Prevailing cultural norms—particularly those related to teaching and learning—also play an important role in intellectual development [4, Ch. 5]. If the dominant instructional paradigm in pre-college education is based on the notion that the teacher's job is to impart information and the students' job is to absorb and repeat it, and if this is the only type of instruction students see in their K-12 education and its validity is not contradicted in their homes, they are likely to enter college as received knowers (dualists) and to be resistant to efforts to change them. On the other hand, if they are subjected to schooling that encourages and facilitates independent, critical, and creative thinking, they are much more likely to enter college at higher developmental levels. If intuition is disregarded by most of society as a valid source of information, or if challenging authorities is a widespread and culturally acceptable phenomenon (as it was on college campuses in much of the 1960s and 1970s), or if asking instructors or peers for help is considered a sign of weakness within a cultural subgroup, it is bound to affect a student's readiness to move out of an intellectual stage that reflects those points of view.

It has long been known that students' intellectual development can be strongly influenced by their emotional states. Emotion drives attention, which in turn drives learning and memory [24]; students who are depressed or angry do not take in and process information effectively, and students' scores on a test of optimism were better predictors of first-year college grades than were Scholastic Aptitude Test scores or high school grades [26]. Moreover, an accepting and supportive classroom environment has been found to enhance both academic achievement and intellectual development [27,28]. These findings and those related to social and cultural influences will be important when we later offer recommendations for things instructors can do to facilitate intellectual growth in their students.

F. Assessing Developmental Levels

Methods of assessing an individual's level of intellectual development have been developed for each of the models discussed. The original methods all involved conducting and transcribing open-ended interviews and using trained raters to assign levels to the interviewees. Interview transcription and analysis remains the most reliable and valid approach to assessment, but the difficulty and expense of this approach has motivated efforts to design questionnaires and multiple choice instruments that can be inexpensively administered to large numbers of students. Alternatives to interviews include the *Measure of Intellectual Development* (MID) for the Perry model [29] and the *Measure of Epistemological Reflection* (MER) for the Baxter Magolda model[30,31], in which students write essays on topics derived from the interview protocols that are rated in the same manner as the interview transcripts, and the *Learning Environment Preferences* (LEP) questionnaire [32] and *Reflective Thinking Appraisal* [33], objectively scored Likert-scale instruments for assessing levels on the Perry and Reflective Judgment (King-Kitchener) models, respectively. While these assessment tools have the desired advantages of relative ease of administration and low cost, the ratings obtained using them tend to be one to two positions lower than those obtained with interviews and correlate moderately at best with the latter ratings [34, 35].

Noting the poor correlations between interview-based ratings and ratings obtained with pencil-and-paper (P&P) instruments, Pavelich, Miller and Olds [35] formulated an innovative software-based tool called *Cogito* for assessment of levels on the Perry and Reflective Judgment models. The on-line instrument asks questions about scenarios related to four controversial issues, collects responses, asks subsequent questions based on the responses to previous ones, and uses a neural network to identify response patterns and match them with patterns of responses submitted by individuals with known Reflective Judgment and Perry levels (based on structured interviews). The object is to filter out the "noise" associated with unexplored, first-response data (simulating the filtering that takes place in structured interviews by listening, probing experts) and thereby to achieve a higher correlation with interview-based ratings than P&P instruments have been able to provide. Unfortunately, while the correlation coefficient of about 0.5 (obtained when the best of a variety of options tested was used) was indeed higher than the values obtained for the P&P instruments, it was still well below the desired minimum value of 0.8. The authors stated that they were working on more sophisticated approaches to the data analysis, but also speculated that 0.5–0.6 might be an upper bound to the correlation coefficient between ratings obtained using objectively-scored instruments and interviews.

The validity of intellectual development assessment is critically important if research is to be based on the assessment data, and it may also be significant if the results for an individual student are to be used to guide the provision of academic support or counseling. On the other hand, if the goal is to facilitate intellectual growth for a collection of students—for example, all of the students in a class—then having a valid assessment (or any assessment at all) of individual students' levels may not be essential. It is enough to know that in almost any college-level engineering or science class, students are likely to be found at all levels from received knowing to contextual knowing (or from Level 2 to Level 5 on the Perry scale), and so balanced instruction should be designed to address the needs of all of those students. What such instruction might consist of is the subject of the rest of this paper and the next one in the sequence [2].

III. PROMOTING INTELLECTUAL GROWTH: THE GOAL AND CHALLENGE OF EDUCATION

Table 2 summarizes results of two studies in which the Perry levels of beginning and advanced engineering undergraduates were assessed. These results suggest that most entering engineering students are near Perry Level 3 (multiplicity subordinate), only beginning to acknowledge that not all knowledge is certain and still relying heavily on authorities as sources of truth. The studies also suggest that the average change after four years of college is one level, with most of the change occurring in the last year.

Table 2. Perry Levels of Engineering Students

Year (n)	Average Perry level (SD)	% at Level 5	Reference
1 (45)	3.27 (0.44)		Pavelich & Moore [8]
2 (34)	3.71 (0.53)		
4 (46)	4.28 (0.70)	25%	
1 (21)	3.27 (0.40)	0%	Wise *et al*. [9]
3 (21)	3.33 (0.35)	0%	
4 (21)	4.21 (0.50)	33%	

As we have noted, Belenky *et al.* [15] and Baxter Magolda [20] propose that men and women exhibit different developmental patterns. Data for eight male engineering students and eight female engineering students who completed a first-year project-based design course support this observation [9]. There was initially no appreciable difference between the two groups in average Perry rating or SAT scores. At the end of the first year, that 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 that for the third year came close ($p = 0.054$), but 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 previous contentions that the early engineering curriculum is less effective for women than for men.

Most academicians would agree that these findings do not reflect well on the effectiveness of the subjects' college education. Rather than considering science and engineering to be mere collections of facts to be memorized and formulas to be blindly applied (as students at the lowest developmental level see them) or making superficial use of evidence to arrive at final judgments (in the manner of students at intermediate levels), the graduates should view science and engineering as processes of inquiry. When performed correctly, these processes involve using the best available evidence to reach conditional acceptance of hypotheses and models and remaining constantly open to reconsideration of conclusions if new evidence is forthcoming. This attitude exemplifies the type of thinking associated with contextual knowing (Level 5 and higher). The implication is that science and engineering educators should adopt as a primary goal doing a better job of promoting the intellectual growth of their students than has been done in the past.

There are other arguments for moving students to higher levels of intellectual development. Research studies on the King-Kitchener model show correlations between development of reflective judgment and growth on other dimensions, including moral reasoning, multicultural awareness, and tolerance for diversity [19], all attributes generally seen as desired outcomes of an effective education. Anything schools and instructors can do to equip their students with reflective judgment also has the potential to increase the likelihood of attaining those outcomes.

The process of intellectual growth is complex. It involves changes in students' intellectual skills and in their attitudes regarding the roles of authorities, peers, and themselves in constructing and imparting knowledge. It is strongly influenced by aspects of classroom instruction, including the types of tasks students are assigned, the clarity with which expectations are communicated to them, and the degree to which the classroom environment supports them as they attempt to respond to the unfamiliar demands being placed on them. Intellectual growth is also influenced by factors external to the classroom, including interactions with peers, cultural norms related to teaching and learning, and students' emotional states, as well as students' interpersonal skills (e.g., how they respond to suggestions and criticism), levels of maturity, self-authorship (acceptance of responsibility for constructing and integrating their own beliefs, attitudes, and understanding), self-confidence, and self-discipline [23]. While recommendations for educators and counselors have been written that address all of these points [25,36], we will henceforth concentrate on issues directly related to classroom instruction.

The principal catalysts for students' intellectual growth are challenges 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 spontaneously accept the reality of multiplicity and move to transitional knowing, and 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.

Challenge alone may not be enough, however. Intellectual development is not a neat linear phenomenon, but a complex wave-like motion characterized by periods of advancement interspersed with periods of suspension or even reversal of growth that may last for a year or more, and advances may take place in some aspects of knowledge and reasoning but not others. Perry [3] defines three alternatives to growth: *temporizing*, in which students are aware of the forces impelling them to change and perhaps of the need for them to do so but hesitate to make the step; *retreat*, in which they reject those forces and take refuge in the thought patterns of a lower position on the scale (often an aggressive retrenchment to the *we-they* dichotomy of dualism); and *escape* (or *alienation*), in which they hide behind the "all opinions are valid" viewpoint characteristic of multiplicity, avoiding the responsibility to seek and weigh evidence carefully when making judgments. Temporizing is a transient state that ends with either growth, retreat, or escape. Retreat and escape may be (and ideally are) temporary positions that end with a resumption of growth, but they may also be permanent.

The task for instructors is thus to provide enough *challenge* to students' ways of knowing to stimulate them to move to higher levels, but not so much as to paralyze them in a temporizing state or drive them into retreat or escape. A parallel task is to provide an appropriate level of *support* for their efforts to confront the challenge, confirming their ways of knowing to an extent that empowers them to relinquish their exclusive reliance on authority, but not to an extent that enables them to adapt all new ideas to their current level [37].

IV. SUMMARY

As they go through college, most students undergo a developmental progression in their attitudes toward teaching, learning, and knowing. Four models described in this paper, formulated by Perry [3], Belenky *et al*. [15], King and Kitchener [17], and Baxter Magolda [20], outline the course of this progression. The models differ in some details, but paint a more or less consistent picture. Many students enter college at the level of (in the terminology of Baxter Magolda) *absolute knowing*, believing that knowledge is certain, authorities (competent teachers) have the knowledge and the responsibility to communicate it, and the students' job is to absorb it and repeat it. As they experience the stimulations and challenges of their college courses and extracurricular activities, the students may progress through some or all of several successive stages in which they gradually relinquish their belief in the certainty of knowledge and the omniscience of authorities, recognize the necessity of making judgments based on evidence, and become increasingly adept at gathering and analyzing the evidence. There are two patterns of development described in the models, one characteristic of more women than men and the other of more men than women, but the final level, which Baxter Magolda terms *contextual knowing*, is the endpoint of both patterns. At this level, individuals reject the notion of absolute truth and recognize that all knowledge is contextual. They take responsibility for making their own judgments, gather and interpret evidence from a wide variety of sources (research, personal experience, and ideas of others whose expertise they acknowledge), and accept that their judgments must be considered conditional and liable to change if new evidence is forthcoming.

The list of characteristics of contextual knowing just stated could serve as a definition of what expert scientists and engineers do. It follows that instructional programs wishing to prepare graduates to be expert scientists and engineers should be designed to promote the intellectual development of their students. Unfortunately, many science and engineering courses emphasize facts and well-established procedures and do not routinely call on students to confront the uncertainty of knowledge and the need to make evidence-based judgments in the face of that uncertainty. The result is that most students graduating from college do not progress much beyond the intellectual level at which they entered.

Promoting intellectual growth requires challenging students' beliefs about the nature of knowledge, the role of authorities, and the procedures that should be used to make judgments. This requirement poses a dilemma for instructors. In any college class, students are likely to be found at all levels of intellectual development from absolute knowing (Level 2) through contextual knowing (Level 5). Instruction that might be ideally suited to students at one level could be ineffective or counterproductive for students at another.

For example, students at Level 5 might flourish in a classroom environment based on cooperative and problem-based learning, in which the students are confronted with exclusively high-level open-ended problems and are given guidance by the instructor when it is needed but are basically left to find their own way. Level 4 students might also do well in this environment: they might be uncomfortable at first, but meeting the attendant challenges could promote their progression to Level 5. Level 2 students and many Level 3 students, on the other hand, might find such an environment uncomfortable enough to derail their learning. (See Felder [6], for an illustration of this situation.) But the answer is clearly not to teach exclusively in a manner that students at Level 2 would find comfortable: presenting facts and formulas in lectures, assigning only single-answer problems involving those facts and formulas, and putting nearly identical problems on the tests. Level 2 and many Level 3 students might be happy with this approach but would not experience any intellectual growth as a result of it, and most students at the higher levels would be bored to death. The key is to provide an appropriate array of challenges to students at all levels.

Challenge alone is not sufficient, however. Unless appropriate support is provided to help students deal with the changes they are being called upon to make, their resolve to stay where they are could simply be stiffened or they might even retreat to lower developmental levels. Giving up fundamental and firmly held beliefs is one of the hardest tasks faced by human beings—arguably the hardest task of all. Science and engineering instructors may (and frequently do) adopt a sink or swim mentality, teaching at a high level and forcing the students to either adapt or drop out, but a far more promising approach is to include explicit mentoring in the ways of thinking being promoted. The questions are, what sort of mentoring is required, what is the best way to provide it, and most difficult, how can a single instructor achieve the appropriate balance of challenge and support in a class with the diversity of attitudes and needs that characterize students who span the full spectrum of intellectual levels? These questions will be addressed in the next paper in this series [2].

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