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The Intellectual Development of Science and Engineering Students: Part 1: Models and Challenges

PART 2. TEACHING TO PROMOTE GROWTH

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As they go through college, most students undergo a developmental progression in their attitudes toward teaching, learning, and knowing. According to a model formulated by Marcia Baxter Magolda,[3] a student may go through some or all of four developmental stages, exhibiting either of two gender-related patterns of behavior in all but the last stage.

· **Absolute knowing**. All knowledge that matters is certain; all points of view 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. In the *mastery pattern* (exhibited by more men than women), students tend to raise questions to make sure their information is correct and challenge deviations from their view of the truth, and in the *receiving pattern* (more women than men), students are more likely to simply take in and record information without questioning or challenging it.

· **Transitional knowing.** Some knowledge is certain and some is not. Authorities have the responsibility to communicate the certainties, and the students must make their own judgments regarding the uncertainties. In the *impersonal pattern* (more men than women), students make judgments using a logical procedure prescribed by authorities and believe that they deserve full credit if they follow that procedure, regardless of the clarity of their reasoning and the quality of their supporting evidence. In the *interpersonal pattern* (more women than men), students base judgments on intuition and personal feelings and distrust logical analysis and abstract reasoning.

· **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 tend to do so superficially, and they believe that when knowledge is uncertain all conclusions regarding it are equally good if the right procedure is used to reach them. In the *individual pattern* (more men than women), students rely on objective logic and critical thinking, challenging their own and others' positions to establish truth and make moral judgments. In the *interindividual pattern* (more women than men), students rely on caring, empathy, and understanding of others' positions as bases for judgments.

· **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 conclusions if new evidence is forthcoming.

The list of characteristics of contextual knowing could serve as a definition of what expert scientists and engineers do. It follows that instructional programs wishing to prepare graduates to be 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.

A necessary condition for a student's intellectual growth is *challenge* to the beliefs that characterize his or her current level. Students who believe that all knowledge is certain and all problems have solutions must be challenged with issues that cannot be neatly resolved and open-ended problems that have many possible acceptable solutions. Those who think authorities are omniscient and infallible must be made aware that experts—including their instructors—make mistakes, cannot solve all problems, and frequently disagree with one another. Those who believe that when knowledge is not certain all opinions are equally valid must be challenged to provide evidence to support their judgments and should be evaluated based on the quality of the evidence they provide. Challenge is not enough, however: students confronted with challenges to their basic beliefs may feel threatened and either persist at their current developmental levels or retreat to even lower levels. To avoid these outcomes, appropriate emotional *support* for students should accompany challenges to their beliefs.

Part 1 of this two-part series of papers reviews Baxter Magolda's model in detail, shows how it parallels and integrates several other more widely known models formulated by Perry,[4] Belenky *et al*.,[5] and King and Kitchener,[6] and discusses the applicability of the models to science and engineering education. Part 2 formulates an instructional model for providing the challenge and support needed to promote intellectual development. The model comprises the following five elements:

1. Variety and choice of learning tasks. Assigning tasks that cover the full developmental spectrum assures that each student will be appropriately challenged at least some of the time. Assignments should vary in type (closed- and open-ended problems, straightforward problems and problems that call for creative and/or critical thinking) and level of structure (well-defined problems and incompletely or ambiguously defined problems). Making the exercises as relevant as possible to students' backgrounds, interests, concerns, and career goals helps motivate the students to take them seriously, and providing some choice in the assignments helps minimize the frequency at which students are forced to work at levels too high or too low for their current level of development.

2. Explicit communication and explanation of expectations. The better the students know and understand what they are expected to do, the greater the likelihood that those with the necessary aptitude will end by being able to do it. Instructors can clarify their expectations by writing instructional objectives (explicit statements of the things the students might be asked to do in assignments and on examinations to demonstrate their mastery of the course content), sharing the objectives related to exams as study guides, and including a representative subset of the objectives in the assessments. If high-level objectives are included in the list and clearly linked to the assessment in this manner, most students will pay attention to them and do their best to prepare to meet them.

3. Modeling, practice, and constructive feedback on high-level tasks. When high-level problems are to be assigned, the instructor should model in class the types of thinking expected from the students and give the students practice exercises of the same type in class and in assignments. To equip students with mastery of a high-level skill by graduation, modeling, practice, and feedback in that skill should begin in the freshman year and should become more frequent as the curriculum advances. Once the instruction has been provided in a course, the skill should be included in the learning assessment done for the course and the students' mastery of the skill should count toward the course grade, if only by a token amount.

4. A student-centered instructional environment. Requiring students to take more responsibility for their own learning promotes the decreasing reliance on authorities that characterizes intellectual development. An effective way to do so is to use an inductive learning approach: present observations and experimental data and help students formulate models and infer underlying principles and theories, and present fundamental material (math, basic science) only after a need to know it has been established in the context of realistic and complex problems. Examples of this approach include *problem-based learning, project-based learning, guided inquiry*, and *discovery learning*. Other effective student-centered approaches include *active learning*, in which lectures are partially replaced with course-related activities during class, and *cooperative learning*, in which students work on assignments and projects in teams under conditions that assure (among other things) individual accountability for all the learning supposed to take place. The learning benefits of these approaches, including their role in helping students acquire and improve higher-level thinking and problem-solving skills, have been well established by research.

5. An attitude of respect and caring for students at all levels of development. Most studies of teaching effectiveness agree that students' perception of an instructor's respect and caring is a vital factor in promoting every conceivable measure of student achievement, self-confidence, and satisfaction. Unless instructors augment their challenges to students' beliefs with measures to convey a sense that they care about the students and are willing to help them meet the challenges, the students are likely to feel threatened and stiffen their resistance to change. Some supportive measures are embedded in the previous conditions, including modeling and giving extensive practice in the desired types of thinking and providing some choice in assignments, but even more important is establishing an atmosphere of respect and caring. Ways of doing so include learning students' names, soliciting their viewpoints regarding class policies and procedures and being open to their ideas, setting up opportunities for student-faculty interactions in and out of class, and being fully present with them during interactions that may arise.

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