Students’ Epistemologies in Science and Engineering: Paths to Responsibility and Connection

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Abstract:
Different “ways of knowing,” or epistemological modes, have been revealed in previous studies of undergraduate students. In this paper, possible effects of paradigmatic science and engineering pedagogy on undergraduate students exemplifying different epistemological modes are proposed. It is suggested that some prevalent assumptions in science and engineering education act preferentially against women students and work to suppress critical thinking among students of both genders. A new, longitudinal study is described that will reveal the epistemological modes inhabited by undergraduate students at a science and engineering university. Potential reciprocal effects among undergraduate development, the longitudinal study, and the technical disciplines themselves are suggested.

Keywords: learning, longitudinal studies, science and engineering, undergraduates, women

INTRODUCTION

In the landmark book, Women’s Ways of Knowing, an undergraduate student is quoted as remarking, “science is not a creation of the human mind” [1]. The implications of this perception for ethics are profound: in the failure to acknowledge ownership of the scientific process, the student and the many others like her who view science as an objective search for a fixed, externally given truth are preparing themselves to relinquish responsibility for the products of their efforts, to abandon the children of their minds.

In addition, the bias indicated by the remark suggests one reason women students leave science and engineering for other fields: the prevalent “banking” model of science teaching, which sets up knowledge as something to be dispensed instead of created, alienates students who are skilled in constructing knowledge relationally or contextually.

This paper raises questions about knowledge and self-knowledge in undergraduate science and engineering programs and describes a new, longitudinal study that will begin to address these questions.

I.

In trying to understand undergraduate science and engineering education and the paths women students create for themselves, it is not sufficient to examine what students know; it is also necessary to ask the question, “how do they know?” Studies of undergraduates’ epistemologies reveal that the way a student knows is not static, but rather changes and develops over her time as an undergraduate [2,3,4,5]. The epistemological modes present in a student population are multiple, ranging from the perception that truth is fixed and absolute, that professors are unassailable sources of truth, to the acknowledgement that truth is contingent, contextual, and constructed, that authority is established through transaction.

These modes impact not only how academic knowledge is known, but also how students know, understand, or interpret their personal experience, their peer relationships, and their relationship to authority. A student’s epistemological mode is not fixed and unchanging, but neither is its course of change quantifiably predictable. Rather, examining students’ epistemological change provides qualitative insights into the process of development during the college years.

The starting point we use here to raise questions about undergraduate students’ epistemologies is the model presented by Baxter Magolda in her monograph, Knowing and Reasoning in College: Gender-Related Patterns in Students’ Intellectual Development [6]. This model will be referred to as the Epistemological Reflection (ER) model in the discussion that follows. Baxter Magolda developed this model over the course of a five-year, longitudinal study of undergraduate students at Miami University in Oxford, Ohio.
In the ER model, Baxter Magolda identified four modes of knowing, or epistemological modes, exemplified by the undergraduate students interviewed in her longitudinal study: “absolute knowing,” “transitional knowing,” “independent knowing,” and “contextual knowing.” Within absolute knowing, Baxter Magolda found two distinct, gender-related reasoning patterns: “receiving” and “mastery.” Within transitional knowing, the two reasoning patterns are “interpersonal” and “impersonal.” Within independent knowing, the patterns are “interindividual” and “individual.” The two, approximately parallel streams of reasoning patterns found in the first three modes may merge in the fourth mode of contextual learning.

Students exemplifying Baxter Magolda’s “absolute knowing” mode conceive of truth as a black-and-white affair. Knowledge is objective, and the professors are the authorities and purveyors of knowledge. “Receiving pattern” absolute knowers try to record all the information presented by the professor. They also want opportunities to demonstrate what they have learned through evaluations. They tend to find peers’ interactions in class helpful only insofar as they facilitate the transfer of information from the professor. “Mastery pattern” absolute knowers enjoy challenging and being challenged by their peers in order to master the knowledge presented. They identify themselves with the authority figure of the professor and attempt to emulate that authority by mastering the material. They are more verbally oriented toward their instructors than receiving-pattern students, finding it important to demonstrate their interest in the subject to the professor. The receiving pattern in the Baxter Magolda study was exemplified more often by women than by men; the mastery pattern was employed more often by men than by women.

“Transitional knowing” describes students who find some areas of knowledge to be uncertain and others as certain. Students in this mode show a desire to understand the material, instead of merely to learn it. Within the transitional knowing mode, the “interpersonal” pattern of reasoning was found more often among women and the “impersonal” pattern more often among men. The patterns are distinguished through differences in valuation of relationships and perceived distance from authority:

Interpersonal-pattern students care about their classmates’ perspectives, want to know their peers, and hope that instructors will care about them. Relationships are central to the learning process because knowing others promotes sharing perspectives and sharing perspectives increases knowledge. If instructors are uncaring, teaching (and thus learning) is ineffective. For impersonal-pattern students, challenge is more important than relationships. This emphasis appears to reflect the impersonal-pattern students’ concern for individual learning, whereas the interpersonal-pattern students focus on the relationships made possible during learning [7].

The “independent knowing” mode evidences considerable uncertainty and relativity. In this mode, students no longer see professors and other external authorities as the sole sources of knowledge; rather, students inhabiting this mode often contend that all opinions are valuable. For students exhibiting the “individual” reasoning pattern, entering this mode means learning to listen to other peers’ ideas in addition to their own. For other students, those exhibiting the “interindividual” reasoning pattern, entering the independent knowing mode represents the first time they consider the possibility of their own authority. This student’s comment exemplifies the interindividual pattern:

I’m a little more outgoing as far as if I have an opinion. Before, I would either go along with everyone else, or I would just keep quiet. Not that I walk around telling everyone what I think, but I’m just more outgoing socially. And if I have an idea, I’m not afraid to say what it is [8].

The relatively few students in Baxter Magolda’s study who exhibited “contextual knowing” exemplify what many call “critical thinkers.” In judging the value or validity of existing knowledge, they look to their own experience and knowledge in addition to seeking out informed others. They couple knowledge and context and refrain from “transfer[ring] ideas to new situations without reevaluating their validity” [9]. They require claims, their own or others, to be substantiated in their relevant context. Although the small number of students exemplifying contextual knowing precluded Baxter Magolda from identifying possible, distinct reasoning patterns within the contextual knowing mode, she points out the logical possibility that the parallel pattern structures, receiving-interpersonal-interindividual and mastery-impersonal-individual may merge in this epistemological mode. As interindividual-pattern students move to contextual knowing as they develop their appreciation of their own voice and ability to construct knowledge, individual-pattern students complete this move as they develop their appreciation of and more fully engage their peers’ voices and authority.

II.

Is it important or good for students to develop
toward ‘higher’ epistemological modes? In contrast to Perry’s stages of intellectual and ethical development, Baxter Magolda’s ER model avoids numbering the four ways of knowing it describes. This is done to represent the rejection of the objectivist paradigm, to indicate that the model’s purpose is not to generalize student experience, and, perhaps, to emphasize the qualitative nature of the research. Baxter Magolda does not, however, claim to put forward a value-free model. The ER model describes ways of knowing of increasing complexity, with the contextual knowing mode being the most complex. Other transformations are intrinsically linked to the progression from absolute knowing to contextual knowing: the student’s discovery and development of voice, his ability to relate to and learn from peers, and her grounded perception of herself as authority or expert within specific contexts. These changes are valued as positive, significant developments to be encouraged. Thus, in addition to its descriptive content, the model also has a specific, normative effect, projecting its constructivist theoretical basis.

Robert Kegan suggests that encouraging this development among undergraduates may require an environment that confirms their current way of knowing while presenting enough contradiction to that mode to allow and engender forward-moving change [10]. What environment does the current paradigm of science and engineering undergraduate education provide, and how might this environment affect student development? Certainly, the absolute knowing mode is compatible with most science and engineering lecture courses. Students exemplifying both the mastery and receiving patterns would feel at home in a lower-division lecture, where knowledge is presented to be remembered and later recalled. Beginning with students in the mode of transitional knowing, various dissonances may appear. Students may separate their technical courses from their other courses so that their learning experiences harmonize with their expectations:

I don’t particularly care for humanities, English or stuff. There’s a lot of–the answers are–they can vary. There’s no right or wrong answer. I like things where there’s a right answer. Like in chemistry, there’s a right answer, but in other classes there’s not [11].

But interpersonal-pattern students would be less likely to find technical courses, situated in a culture of objectivity, to their liking. The impersonal, “subject matter” orientation of the typical technical course would manifest in the interpersonal-pattern student’s inability to succeed or excel in the course and a poor evaluation of teacher effectiveness. This discomfort would not exert a positive developmental pressure on the interpersonal-pattern student, however. Along the parallel courses of reasoning pattern development, the interpersonal-pattern student moves to the interindividual pattern upon entering the mode of independent knowing. As described above, moving from the interpersonal pattern to the interindividual pattern is associated with recognizing voice in the self. The objective focus of the technical course may provide too harsh a climate for this recognition to occur. Recalling that the interpersonal pattern is found more frequently among women than among men, we find a possible point of gender selection. The student may remain in the discipline, uncomfortably inhabiting the interpersonal mode, or she may leave to focus her attention elsewhere.

The modes of independent knowing and contextual knowing both depend on a plurality of sources of knowledge. Independent knowing is characterized by a sense of relativity: all opinions have some merit. With the change to contextual knowing, the student begins to understand herself as an authority within specific contexts, taking part in the creation of knowledge. The expertise of others, including the professors, is now bracketed, also standing within a specific context. Outside of the relatively limited experiences of undergraduate scientific research and engineering design programs, it is reasonable to ask if it is even possible for a student to progress into the independent knowing or contextual knowing modes in the current, paradigmatic environment of the technical disciplines.

Courses within the technical discipline are not the only classes that science and engineering undergraduates take, and other classes may be conventionally structured in ways that are more conducive to development into the more complex modes of thinking. Discussion-based seminars and other courses in humanities disciplines, where the problematic aspects of objectivity are directly engaged, may provide students the necessary environment for epistemological development, simultaneously supporting and challenging the student’s present way of knowing. And the classroom is not the only learning environment for the college student. The rich and varied experiences interacting with peers and others outside the classroom often provide a counterpoint to the student’s academic experience, sometimes resulting in the productive dissonance that promotes epistemological development.

Still, this suggests that students progressing to more complex ways of knowing may do so in spite of their
technical courses, receiving their developmental nourishment in other academic disciplines or in their co-curricular experiences. Given the prevalent pressure on science and engineering students to focus on their technical studies and to sideline or even devalue other disciplines (and hence, indirectly, other ways of knowing), the current paradigm may select against students exhibiting independent and contextual knowing. Some of these students may then find no alternative but to choose other educational and career paths where they believe their potential and contributions are valued.

III.

If selection against independent and contextual knowers occurs within the conventional undergraduate technical curricula, what are the implications for the futures of these disciplines? Assuming that a discipline is at least partially shaped by its practitioners, the technical disciplines will lack the input of contextually aware voices, members who might be able to critically evaluate the discipline and forge vital connections to the evolving fields of knowledge in other disciplines. The objective and impersonal paradigm is thus self-reinforcing, and personal responsibility within such a discipline will be limited to a single context dominated by objectivity. The foundation of ethics, requiring a wider awareness of context, goes wanting.

What to do? The initial course we have chosen is to ask the questions that raise critical awareness in students and the local academic community. In approaching undergraduate science and engineering pedagogy, it is not beneficial or necessarily even possible to transfer the ER model and its prescriptive findings from its original context into that of a science and engineering school. Attempting to implement reform according to the ER model might inadvertently reinforce the objectivist paradigm, one that is comfortable applying generalizations to specific contexts. Instead, we start by trying to identify what ways of knowing are actually present in the undergraduate population of our university, using the ER model as a guide. The ER model is well suited to this purpose, because: first, the constructivist basis of the model opens it to identifying forms of knowing it does not explicitly describe or to using other forms of interpretation should the need arise; second, the model includes both genders, and third, the model was developed longitudinally.

These questions are structured as components of a new, qualitative study of epistemological reflection. This qualitative study we are starting at the New Mexico Institute of Mining and Technology employs the Measure of Epistemological Reflection (MER), a written instrument developed by Baxter Magolda consisting of six questions with follow-up questions [12]. As recommended in the parallel criteria for “goodness” appropriate to this type of qualitative research, interviews with some of the participants will be used to evaluate and enrich readers’ analyses of responses [13]. These interviews will be recorded to facilitate these analyses. Approximately 80 first-year undergraduate students, 40 men and 40 women, will be invited to participate by letter or email. The MER, and interview, when performed, will be administered to participants once per year for five years. Through this study, we hope to identify the epistemological modes exhibited by undergraduate students at our science and engineering university.

This new study’s method and content are in a very real sense not separable; nor is the study impersonal or “objective.” By engaging students in questioning their ways of learning and knowing, the students will begin to investigate elements of the begged questions of their education. Asked how they know, they entertain the possibility of knowing in a different way. Thus, performing the study creates an environment conducive to the emergence and development of voice. It also encourages the critical reflection essential to students’ perception and contextualization of their own authority and role in creating knowledge.

To the extent that faculty at the university are aware of the study, the “early adopters” among them may wish to incorporate insights from the emerging study into their teaching. Although we hypothesize above that the operating paradigm of undergraduate science and engineering education is not sensitive or responsive to differences in students’ epistemologies, individual teachers may be. What differences in the disciplines, in the environment for women students, and in students’ epistemological development will such individual, good-faith adjustments in teaching practice produce? If the adjustments are conceived as changes in teaching “style” instead of viewing them as qualitative changes in the discipline itself, will the assumed distinction between “teaching style” and “teaching content” merely reinforce the paradigmatic, detached and objective conception of the discipline? Or, by conceiving the way of teaching as part of the content of teaching, will the problem and opportunity of improving one’s teaching open into the larger opportunity and responsibility of shaping the discipline? These are second-order questions that this study will reveal and perhaps suggest ways of addressing.

CONCLUSION
The posited assumptions that scientific disciplines are comprised of closed, impersonal systems of fixed methodologies, that objective truth is available, and that objective truth is exclusively available through the medium of science have far-ranging implications for the vitality of the technical disciplines, and, not independently, for the ability of the technical disciplines to attract and retain women. The presumptions of objective truth and exclusive domain of truth pervade contemporary science and engineering education. These presumptions are not neutral or “value-free,” however, but rather embody and proliferate historically rooted biases. Some of these biases and unexamined assumptions may act preferentially against women students and select against certain epistemological modes or reasoning patterns exhibited by students of both genders.

This paper has presented the description and justification of a new, longitudinal study of undergraduates at a small, science and engineering university. Through questionnaires and interviews, this qualitative study will explore the students’ epistemological modes and gender-related patterns within those modes. The results of the study will help as we begin and continue to formulate hypotheses in response to specific and vital questions: how can science and engineering education be improved to take women students’ needs into account? How can it be transformed so it contributes to the development of thoughtful and responsible practitioners?

References

7. Ibid., 134-5.
8. Ibid., 150.
9. Ibid., 188.
11. Ibid., 106.