excerpt from: **Roth, W.-M.**, & Roychoudhury, A. (2003). Physics students' epistemologies and views about knowing and learning. Journal of Research in Science Teaching, 40, S114-S139. (Reprinted as part of a special issue celebrating the 13 most influential papers published in the journal's 40-year history.)

Task Completion. An important aspect of group work is task completion, which for four students was more important than comprehension (Table 4). When students collaborated, they felt that work could be done three or four times faster. This was of particular importance in the present environment where students designed experiments on their own, with little guidance from preestablished procedures or prepared laboratory equipment. In such an environment it is crucial that there is "A group you can ask . . . but if you are alone you will waste time trying to figure out insignificant details of your experiment." Thus, working in a group "gets the job done on time." According to other students, the additional resources of a group allowed them to design more complex experiments because they could share and thus still end up with reduced workloads. They indicated that more complex experiments were more interesting and gave rise to more learning in a shorter time. Any problems that arose during the work could be resolved much more quickly than if individuals had to solve them on their own. Besides, as groups had more resources than individuals, tasks could be completed more independently from the teacher, and results could be achieved without unduly wasting time waiting for the teacher to help.

Learning to Team-work. Teamwork in the physics classroom prepares students for life. In today's working world, teamwork has become increasingly important. "In the working world, all projects are with other people. Therefore, knowledge of working in groups is fundamental for succeeding in one's occupation." Students felt that learning to work in a team taught them how to build working relationships and how to develop skills for planning and decision making in group situations. Thus, students recognized group work as a preparation for the changing workplace, which is increasingly becoming collaborative (Collins et al., 1989). They felt that the laboratory and group experience provided them with skills that are increasingly important in a complex society.

Toward an Integration: A Grounded Theory This is a summary of content analysis

On the basis of the presented data, we derived a model for the students' conceptualization of physics knowledge and learning (Figure 1). At the top of the diagram we placed the continuum of epistemological commitments to which an individual's view of knowing and learning physics will be related. There are two major aspects of physics knowledge, CULTURAL and INDIVIDUAL. From the students' points of view, both the MATHEMATICAL and the CONCEPTUAL frameworks are culturally mediated and presented to them by TEACHERS and TEXTBOOK (on the left side in Figure 1). Students variously spoke of physics as "a frame of mind and a perception with which to regard facts," a conception of physics that is very close to Kuhn's (1970) notion of paradigm. Students indicated that the MATHEMATICAL and the CONCEPTUAL knowledge can be used in support of each other (see dotted lines in Figure 1). Students with a good mathematical foundation used equations and formulae as efficient organizers of their knowledge. Remembering an equation (MATHEMATICAL), they regenerated the CONCEPTUAL base supporting it. There were also students who indicated that the conceptual physics knowledge underlying mathematical equations and procedures strengthened their understanding of the mathematical manipulations (bidirectional link). Through the subject of physics, mathematics had become concrete. Usually, this knowledge was mediated by using some form of TEXT, provided either by the TEXTBOOK, or by the TEACHER in the form of lectures and blackboard notes, or in additional readings. To acquire mathematical knowledge, both MEMORIZATION of equations and much PRACTICE are needed. To know the conceptual knowledge well, many students felt they had to memorize. In any case, when physics knowledge is viewed as being transmitted by teachers and textbooks in the form of texts,

FIGURE 1

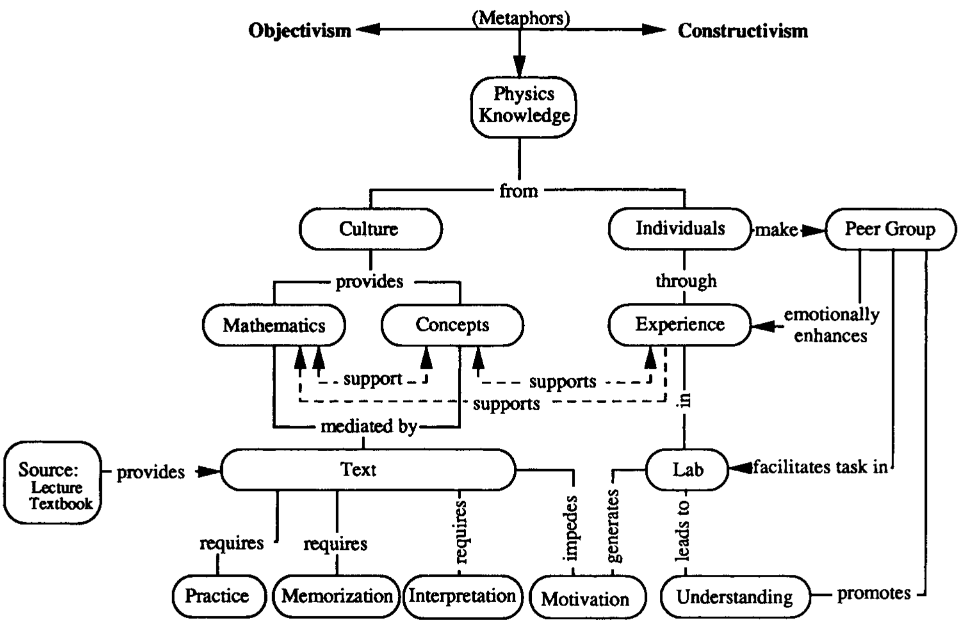

Figure 1. Students' epistemologies and views of knowing and learning physics: A grounded theory.

students felt in a receiving mode, which they disliked for learning the subject matter (impedes MOTIVATION).

The second major aspect of physics knowledge is its tie to personal experience (INDIVIDUALS). In part, this knowledge is intuitive. Physical principles are EXPERIENCED every day because we live in a physical universe. In part, this knowledge can be constructed in the LABORATORY. When knowledge is constructed in this way, it leads to UNDERSTANDING, an understanding that the textbook made of learning physics cannot provide. The direct EXPERIENCE of physics principles may also support the understanding of MATHEMATICAL and CONCEPTUAL knowledge as portrayed in the textbook or by the teacher (horizontal dotted lines in Figure 1). Many students realized, however, that without conceptual knowledge from the text, they would have to re-invent physics completely. Thus, they recognized that conceptual knowledge from the text could facilitate the learning of new principles in the lab (bidirectional link). Equally, although knowledge is generated by individuals, the PEER GROUP was considered an important feature of learning in the laboratory. First, it enhanced individual EXPERIENCE; through discussions and the consideration of multiple points of view, students could discover more on their own and were less dependent on the teacher. The peer group also facilitated the TASK itself, thus freeing the individual to become involved in the understanding side of a lab. Finally, the peer group could bootstrap its performance through negotiation of discrepant interpretation, through peer teaching and learning to new levels of understanding. This mode of learning physics, through individual construction and support of a peer group, was considered highly MOTIVATING.

From an epistemological point of view, the two perspectives are incommensurable. The students clearly talked in terms of the conduit metaphor about the knowledge mediated by teachers and textbooks. As pointed out before, this metaphor, which describes learning as a process of information transfer from an authoritative source to a passive learner, is commensurable with an objectivist view of human knowledge. On the other hand, the students described learning in the laboratory in terms of (a) individual construction of meaning, (b) negotiation of idiosyncratic understanding and interpretation in peer groups, and (c) connections to prior knowledge and the intuitive cognitive framework derived from everyday experience of the physical world. This conception of learning was commensurable with a constructivist view of knowledge, according to which (a) understanding is constructed individually and negotiated in a social forum and (b) knowledge is meaningful and well integrated in the overall conceptual framework of the student. These incommensurabilities between students' views of knowledge and their preferred modes of learning resonate with those described in the section on the nature of knowledge. Although students predominantly portrayed scientific knowledge as absolute, as being or approximating truth, and as existing independently of people, they admitted social influences on the work of the scientist.