Interpreting VASS Dimensions and Profiles for Physics Students

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ABSTRACT

Student views about knowing and learning physics have been probed with the Views About Sciences Survey (VASS) along six conceptual dimensions, and classified into four distinct profiles: expert, high transitional, low transitional, and folk. As an aid to interpreting VASS results, this article provides a qualitative analysis of student responses to items within each of the six dimensions and a quantitative analysis of their relation to students' profiles. Students with an expert profile are chiefly scientific realists and critical learners. Students with a folk profile are primarily naive realists and passive learners. Students with transitional profiles hold mixtures of these views. Student profiles correlate significantly with physics achievement. Indeed, they may be major determinants of what students learn in physics courses.

Keywords: AFFECTS, ATTITUDES, BELIEFS, COGNITION, EPISTEMOLOGY, LEARNING STYLES, PHYSICS, PROFILES, NATURE OF SCIENCE

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Calls for scientific literacy emphasize the interplay between subject-matter on the one hand, and learning styles, beliefs and attitudes on the other (AAAS 1990, 1993; NCEE 1983; NRC 1996; NSTA 1995). Research suggests that: (a) students are often encumbered with views about the nature of science and learning science that are at odds with the views of scientists, and (b) these views may significantly affect what students learn in science courses (Aikenhead 1987; Baker & Piburn 1991; Cobern 1993; Edmondson & Novak 1993; Meichtry 1993; Reif & Larkin 1991; Schibeci & Riley 1986; Songer & Linn 1991). There is a need for valid and reliable instruments to help teachers evaluate instruction in these respects. The *Views About Sciences Survey* (VASS) has been developed for that purpose.

The validity of VASS has been established elsewhere (Halloun & Hestenes 1996; Halloun, Osborn Popp & Hestenes 1997), and VASS data have been analyzed quantitatively with respect to: (a) the statistical significance of grouping student responses into four general profiles, and (b) the relation of these profiles to achievement in science courses (Halloun 1996; Halloun & Hestenes 1996, 1997). This article is concerned primarily with the *qualitative interpretation* of VASS data. Student views about physics and physics learning are analyzed along the various VASS dimensions, and the characteristics of the four profiles and their relation to student achievement are discussed.

VASS profiles provide a comprehensive index of student views about knowing and learning science that can be easily correlated with achievement in science courses. They can thus be used to assess the influence of such views on student learning in science courses, as well as changes in these views due to instruction.

We set the stage for our analysis with a brief discussion of VASS format, dimensions and profile categorization. The main business of this article is then an analysis of VASS profiles within each of the six VASS dimensions supported by student commentary. Then we discuss a broad characterization of VASS results in terms of interrelated scientific and cognitive dimensions. Finally, we present VASS data showing a strong correlation of VASS profiles with achievement in physics courses.

Views About Sciences Survey

The Views About Sciences Survey (VASS) is a paper-and-pencil instrument that probes personal beliefs about the nature of science and about learning science. As shown in Figure 1, beliefs about the nature of science are probed within three *scientific dimensions* pertaining to the structure, methodology and validity of science. Beliefs about learning science are probed within three *cognitive dimensions* pertaining to learnability, reflective thinking and personal relevance of science.

Each of the six dimensions is framed in Figure 1 by pairs of contrasting views which our research has shown to be prevalent among students and scientists (Halloun 1996; Halloun & Hestenes 1996; Halloun *et al.* 1997). Each pair consists of a *primary view* to which most scientists subscribe, and a *contrary view* often held by the lay community and many science students at all grade levels.

VASS contains 30 items, 13 pertaining to the scientific dimensions and 17 to the cognitive dimensions. In constructing a taxonomy of the issues we addressed in these items, we sought to avoid: (a) arcane and problematic questions about the epistemology of science, and (b) bias toward any particular position within the science education community. The items are formulated in a novel Contrasting Alternatives Design (CAD). Each CAD item requires respondents to balance a primary view against a contrary view on the eight-point scale shown in Figure 2. They can pick either alternative exclusively (options 1 or 7), a weighted combination of the two (options 2, 3, 4, 5, or 6), or neither (option 8). Figure 2 shows a typical CAD item in VASS. Details about the development and validation of this new format and various VASS forms are presented elsewhere (Halloun 1996; Halloun & Hestenes 1996; Halloun *et al.* 1997).

To detect possible differences in the views of students in physics, chemistry and biology, there are distinct versions of VASS for each of the three fields. The analysis in this article is concerned only with VASS Form P12 for physics. The data come from administering VASS during 1995 to 27 physics professors, 326 university physics

Scientific dimensions

1. ***Structure:*** Science is a *coherent body of knowledge* about *patterns* in nature revealed by *careful investigation*
   — rather than a loose collection of directly perceived facts.
2. ***Methodology:*** The methods of science are *systematic* and *generic*
   — rather than idiosyncratic and situation specific.

   Mathematics is a *tool* used by scientists for describing and analyzing ideas
   — rather than a source of factual knowledge.

   Mathematical modeling for problem solving involves *more*
   — than selecting mathematical formulas for number crunching.
3. ***Validity:*** Scientific knowledge is *approximate*, *tentative*, and *refutable*
   — rather than exact, absolute and final.

Cognitive dimensions

4. ***Learnability:*** Science is *learnable by anyone* willing to make the effort
   — not just by a few talented people.

   Achievement depends more on *personal effort*
   — than on the influence of teacher or textbook.
5. ***Reflective thinking:*** For meaningful understanding of science, one needs to:
   (a) concentrate more on the *systematic use of principles*
   — than on memorizing facts;
   (b) examine situations in *many ways*
   — instead of following a single approach from an authoritative source;
   (c) look for *discrepancies in one's own knowledge*
   — instead of just accumulating new information;
   (d) *reconstruct* new subject knowledge in one's own way
   — instead of memorizing it as given.
6. ***Personal relevance:*** Science is *relevant to everyone's life.*
   — It is not of exclusive concern to scientists.

   Science should be studied more for *personal benefit*
   — than for fulfilling curriculum requirements.

Figure 1. VASS Taxonomy.

The first thing I do when solving a physics problem is:
(a) represent the situation with sketches and drawings.
(b) search for formulas that relate givens to unknowns.

Answer Options

① Only (a), Never (b); ② Mostly (a), Rarely (b); ③ More (a) Than (b); ④ Equally (a) & (b);
⑤ More (b) Than (a); ⑥ Mostly (b), Rarely (a); ⑦ Only (b), Never (a); ⑧ Neither (a) Nor (b)

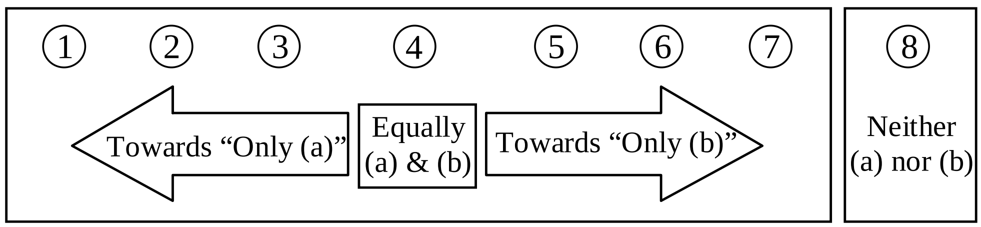


Figure 2. A CAD item from VASS Form P12.

students, 50 high school physics teachers and 2589 students in their classes (Halloun 1996; Halloun & Hestenes 1996, 1997). The teachers, hailing from 23 different states, are participants in the NSF-funded Modeling Instruction project (Wells, Hestenes & Swackhamer 1995).

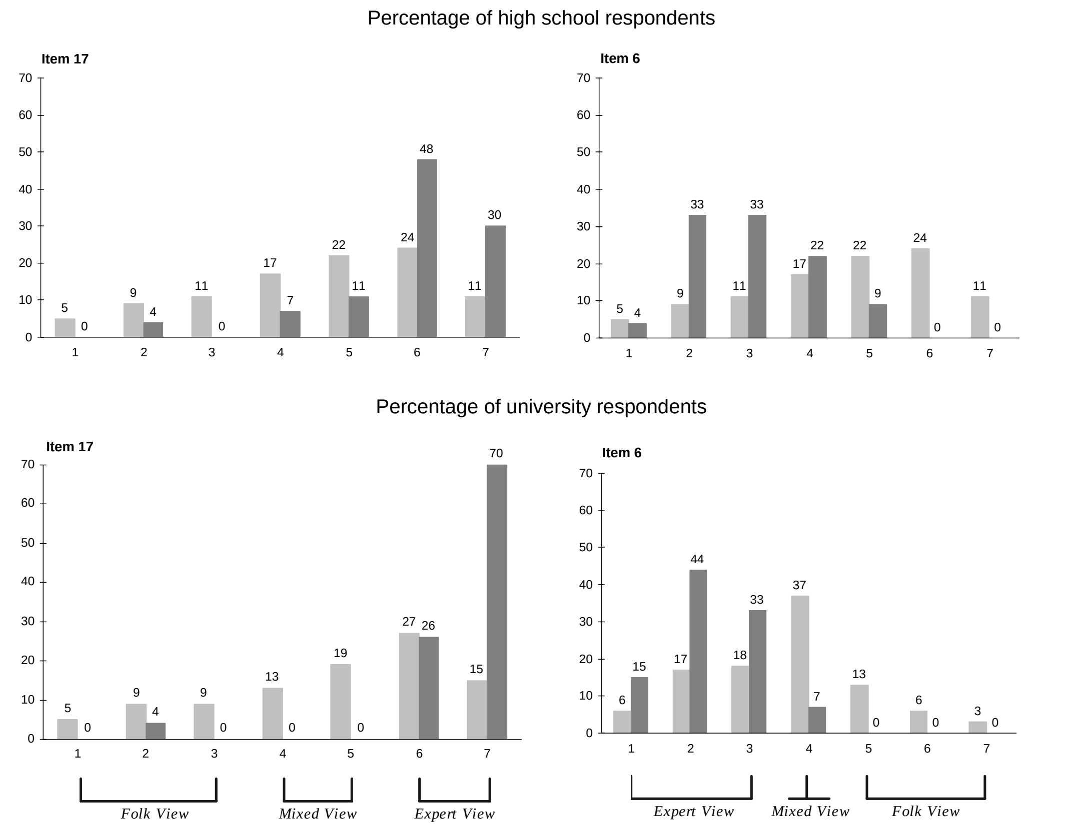
Item Response Classification

VASS was administered to physics teachers and professors in order to establish a standard for comparison with, and classification of, student views. This is illustrated in Figure 3 which shows the distributions of student and teacher/professor responses on two items. Option 8 has been excluded from the analysis because it was chosen by no teacher and less than 2% of students.

The clear differences between college and high school response distributions in Figure 3 are not so pronounced on other VASS items (Halloun *et al.* 1997). In fact, the typical response of the high school teachers is essentially the same as that of the professors on all items. For that reason, we will not distinguish between teachers and professors in the rest of this section. However, it should be noted that the teachers surveyed in this study belong to a select group, so they may not be representative of the typical high school physics teacher.

As illustrated in Figure 3, and based on the nature of the alternatives and teacher answers, student answers on individual items were classified in three types: *expert, mixed and folk* (Halloun 1996; Halloun & Hestenes 1996):

1. Teachers' answers were polarized towards one end of the scale (Fig. 2) on almost every item. On some items, the overwhelming majority chose the extreme option 1 or 7. On others, like those in Figure 3, the large majority was concentrated on two or all three of options 1 through 3, or 5 through 7. Accordingly, a student is classed as holding an *expert view* on a given item if her/his answer falls within these ranges.
2. Except on a few items where one or two teachers selected the opposite to the expert choice (e.g., option 2 in item 17, Fig. 3), the minority of teachers deviating from the expert view were concentrated near the neutral response option 4. A student is classed



17. After the teacher solves a physics problem for which I got a wrong solution:
    (a) I discard my solution and learn the one presented by the teacher.
    (b) I try to figure out how the teacher's solution differs from mine.

6. For me, doing well in physics courses depends on:
    (a) how much effort I put into studying.
    (b) how well the teacher explains things in class.

Figure 3. Physics teacher and student responses on two items in VASS Form P12, and respective item response classification. In all four diagrams, light left bars correspond to students and right dark bars to teachers/professors.

as holding a *mixed view* on a given item if she/he shares the middle position with those teachers who did not express an expert view.

3. A student is classed as holding a *folk view* on a given item if she/he chose a polar opposite to the expert options.

For example, on item 17 (Fig. 3) the *expert view* corresponds to options 6 and 7, the *mixed view*, to options 4 and 5, and *the folk view*, to options 1, 2 and 3. On item 6 the *expert view* corresponds to options 1, 2 and 3, the *mixed view*, to option 4, and *the folk view*, to options 5, 6 and 7.

Profile Classification and Description

As a simple index of overall views on VASS, item responses have been grouped into four types of profiles: expert (EP), high transitional (HTP), low transitional (LTP), and folk (FP). Cutoffs for the four profiles are given in Table 1. They are based on a detailed analysis of data on teacher responses (Halloun *et al.* 1997).

Figure 4 compares profile distributions of high school and college physics students. For the college students, the proportion with expert and high transitional profiles is only about 5% more than for the high school students. Taking attrition into account, this indicates no difference in student views between the high school and college groups (Halloun 1996; Halloun & Hestenes 1996, 1997).

The four profiles are distinguished in Table 1 by the number of items with expert and folk views. These profiles can also be distinguished qualitatively along the six dimensions of VASS (Fig. 1). Of course, the contrast is sharpest between the two extremes: the folk and the expert profiles. A gradual transition from folk to mixed to expert views is suggested by the gradation of views in the two transitional profiles.

Table 1
General profile characteristics

Profile		Number of Items
Type	**Code**	**out of 30**
Expert	EP	19 items or more with *expert views*
High Transitional	HTP	15 to 18 items with *expert views*
Low Transitional	LTP	11 to 14 items with *expert views* and an equal or smaller number of items with *folk views*
Folk	FP	11 to 14 items with *expert views* but a larger number of items with *folk views,* or 10 items or less with *expert views*

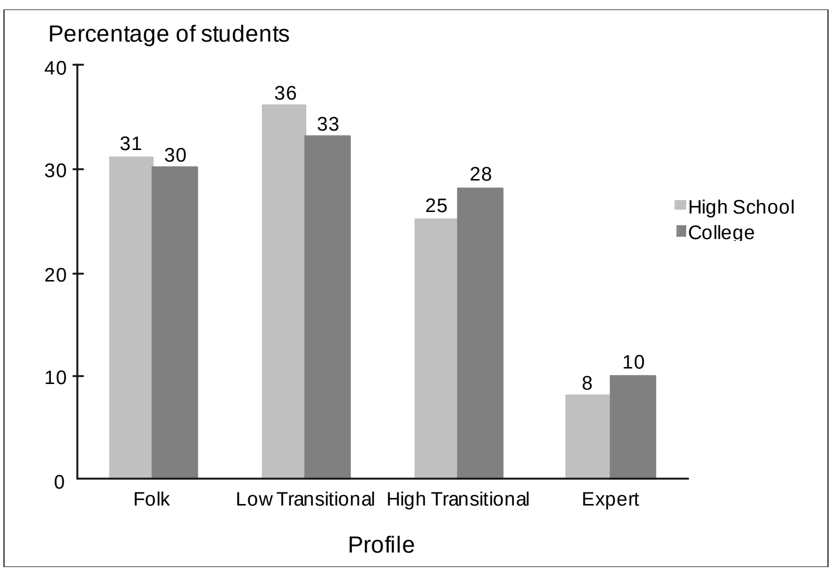


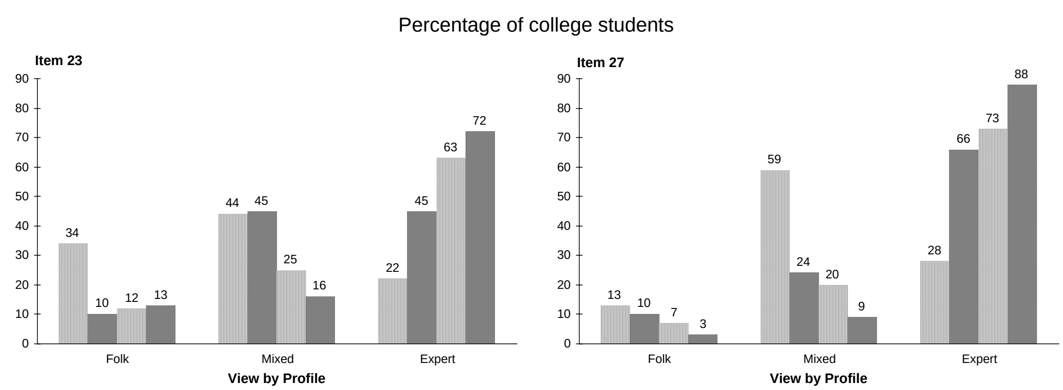
Figure 4. Profile distribution among participating physics students.

In the following we describe qualitative differences between the two extreme profiles along the six dimensions. The differences are first illustrated with the overall distribution of viewtypes in all four profiles on two items in each dimension. Since high school and college data were not significantly different in this respect, only college data are presented in the illustrations. The meaning of these data is then illuminated by excerpts from written response justifications provided by students during the early stages of the development of VASS and from protocols of interviews conducted with some of these students.

The reader is cautioned that our attempt to systematize student views does not necessarily reflect an actual coherence of student views within any given dimension. For instance, not a single student expressed views of the same type (expert, mixed, or folk) on all VASS items, and rarely did a student with an expert profile (EP) express expert views on all items within a given dimension, or did a student with a folk profile (FP) express folk views on all these items. However, EP students consistently expressed more expert views than mixed or folk, and FP students similarly expressed more folk views.

1. Structure

Previous research has shown that student knowledge about topics discussed in physics courses often tends to be situation-specific, concentrated on sensory features of physical objects, weakly structured and fragmented (Halloun & Hestenes 1985-a & b; Hammer 1994; McDermott 1993; Novak 1987, 1994; Reif 1987; Reif & Allen 1992). VASS data suggest that student reactions to physics courses may be limited by an epistemological view that physics consists of a loose collection of directly perceived facts.



23. Physicists say that electrons and protons exist in an atom because:
    (a) they have seen these particles in their actual form with some instruments.
    (b) they have made observations that can be explained by such particles.

27. Different branches of physics, like mechanics and electricity:
    (a) are interrelated by common principles.
    (b) are separate and independent of each other.

Figure 5. Profile distribution across student views about two structure items.

Within each of the three types of item response, the leftmost bar represents the percentage of students with a folk profile, while, from left to right, the other three bars represent the percentages of students with low transitional, high transitional, and expert profiles.

The VASS structure dimension probes specific views about the coherence of science and its relation to the real world. Figure 5 shows the distribution by profile of student views on two VASS items pertaining to the structure of scientific knowledge. Item 23 concerns the way knowledge about the microscopic world is acquired; item 27 concerns

EJ1: *I think we will reach some limit as to what we can observe. Everything is not always the way we see it.*

EJ2: *Without foresight Bohr could not have conceptualized upon the structure of the atom before the invention of the electron microscope.*

EJ3: *If physicists didn't imagine how things could be, then maybe a lot wouldn't have been discovered.*

EJ4: *Imagining how things could be beyond what they observe directly can lead to new concepts and ideas.*

EJ5: *We can learn real world principles by applying knowledge to hypothetical situations.*

EJ6: *Nothing has to be the way it seems... Physics is just our interpretation [of the real world]... It's already there whether we are here or not.*

EI7: *...this one guy, he was developing a chart a long time ago. I forgot the guy's name. He's a scientists and he developed some of the periodic table...and he discovered certain elements before they were actually found. He gave the characteristics of the elements before they were found...because of the behavior of other things that he'd found...and there was like a pattern kind of and he took the pattern farther.*

FJ1: *Everything around us...is exposed to our senses, taste, sight, hearing, etc. Structure of matter won't be a mystery.*

FJ2: *I would imagine that physicists rely too heavily on instruments and don't use their creativity.*

FJ3: *They say beauty is in the eye of the beholder, why not physics too.*

FJ4: *Physicists are completely logical people and cannot accept things that cannot be physically proven [in the sense of being directly perceived].*

FJ5: *Data is based upon observable facts not conjecture.*

FJ6: *If we do not know its existence, then it might as well not be there.*

FJ7: *So far everything has been hypothetical like no friction, no air resistance, no gravity.*

FJ8: *Most info. in freshman courses is impractical for the real world (frictionless surfaces, light rope, etc.).*

Figure 6. Excerpts from student comments related to the structure dimension. These comments were provided by students who expressed either expert views (left column) or folk views (right column) on VASS items. Every comment is tagged with a three-letter code. The first letter indicates whether the student giving the comment had expressed an expert view (E) or a folk view (F) on the original item. The second letter indicates whether the comment was a written justification (J) or an interview excerpt (I). Following numbers designate individual students.

the interconnectedness of physics knowledge. The distribution for item 23 shows that the percentage of students holding the expert view, that knowledge about the microscopic world is inferred indirectly from observations, decreases gradually from the low seventies in the EP groups to the low twenties in the FP groups. Contrasts between the different profiles are a little sharper with respect to the interrelation of different branches of physics (item 27), where the percentage of students expressing the expert view decreases from the upper eighties in the EP groups to the upper twenties in the FP groups.

In the early stages of VASS development, participants were asked to justify their answers in writing. Follow-up interviews were also conducted with student volunteers. Figure 6 shows some student comments related mostly to item 23. These comments reveal that student answers on item 23 are grounded in epistemological beliefs about knowing the physical world. On one end of the spectrum, we have students with the *Galilean* view that, (a) to develop objective knowledge about the real world, we must go beyond what is directly perceived with our senses (EJ1 through EJ4, and especially EI7 in Fig. 6), and (b) we can often make valid inferences about the real world from thought experiments and abstract reasoning (EJ5). Furthermore, some EP students expressed the view that perception is *theory-laden* and that scientific theory provides us with ‘conceptual lenses’ through which we see structure in the real world (EJ5 and EI7). On the opposite end of the spectrum, we have FP students with the *positivist* or *naive realist* position that real things are known only through direct sense perception (FJ1 through FJ6 in Fig. 6). A few students with a folk profile believe that the realm of physics is an idealized, fictitious world of limited practical value (FJ7 and FJ8).

For the global structure of physics knowledge, student comments extended from the expert view that ‘everything is interrelated in this universe’, and thus in physics, to the extreme folk view that no two chapters in any physics textbook are related in any way.

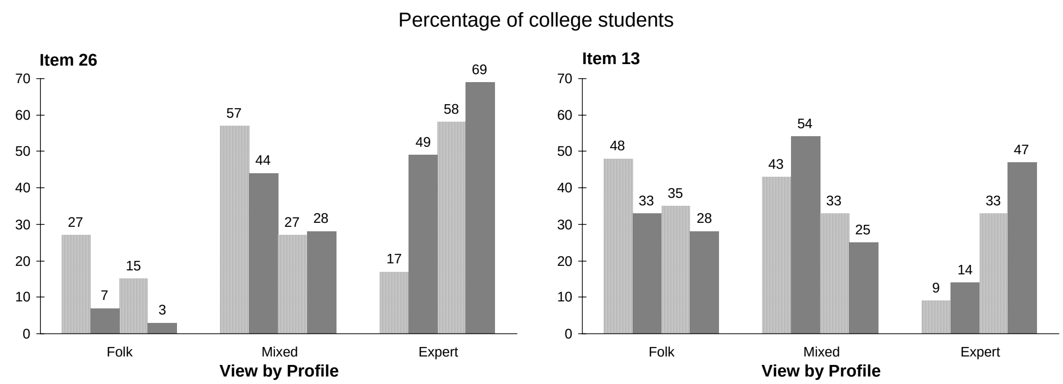
2. Methodology

Students often regard the solutions to physics problems as recipes to be memorized and fail to transfer successful problem solving methods from one problem to another. They often attack problems by searching lists of formulas for given variables rather than constructing clear depictions for the situations at hand (Arons 1984; Chi, Feltovich & Glaser 1981; Hammer 1994; Larkin *et al.* 1980; McDermott 1993; Novak 1987, 1994; Reif 1987; Reif & Larkin 1991; Strnad 1986; Van Heuvelen 1991; Viennot 1985). VASS data suggest that these behaviors may be guided by erroneous beliefs about the methods of physics.

The VASS methodology dimension assesses views about certain processes and tools for developing and applying scientific knowledge. Figure 7 shows the distribution by profile of student views on two items from the scientific methodology dimension in VASS. The two items deal with beliefs about physics problem solving, specifically, with generality of method (Item 26) and approach (item 13). The proportion of student responses to item 26 in accord with the expert view that physics methods are *generic and not situation-specific* decreases gradually from 69% in the EP group to 16% in the FP group. A similar variation, though not with such a sharply distributed EP group, is observed in item 13 with regard to how experts attack a new problem.

Excerpts of students’ written and oral comments about these issues are shown in Figure 8. Comments like EI8 and EI9 reveal that, especially when of the expert type, student views about the methodology of physics tend to be consistent with their epistemological views. Students with an expert profile (EP) who believe in the universality (EI8, in Figure 8) and coherence (EI9) of physics knowledge also believe that the methods of physics are generic and not situation-specific. Such consistency is rarely evident (FJ9) in the views of students with a folk profile (FP). Some FP students even go to the extreme of depending on computer technology to do the thinking for them (FJ10).

In contrast to FP students who rely more on *trial and error* in problem solving (FJ11), EP students realize the importance of relying more on systematic methods that are *transferable* to novel situations (EI10, in Figure 8). *Visualization* of physical situations through the use of sketches and diagrams occupies a central role in the methods of EP students (EJ11, EJ12, EI13) but not of FP students (FJ12 and FJ13). The formula-centered methods of FP students (FJ14 and FJ15) have been reinforced by their experience in physics courses (FJ16, FJ17, FJ18). Indeed, the student with comment EI13 in Figure 8 asserted that, until he got help from his TA, he was ‘still stuck in that realm of applying a formula to a problem because my first instinctual reaction is to grab a formula and start plugging in numbers’.



26. If we want to apply a method used for solving one physics problem to another problem, the objects involved in the two problems must be:
    (a) identical in all respects.
    (b) similar in some respects.

13. The first thing I do when solving a physics problem is:
    (a) represent the situation with sketches and drawings.
    (b) search for formulas that relate givens to unknowns.

Figure 7. Profile distribution across student views about two methodology items. (See Fig. 5 for explanation)

EI8: *A law, a physical law...should apply to all situations...Newton's law applies to basically a pendulum or a thrown ball or an object going around the sun or possibly chemical reactions.*

EI9: *If you group knowledge [around] groups of similarly related objects you can make more or get more information and learn more information about the topic or subject...we group them...based on similarities of the topics through scientific analysis.*

EI10: *In a chemistry course I'm taking, there's a South African dude... I thought I would hit him with something just to try to knock him off balance. I can't, I mean the idea of having this man sit next to me sometimes is aggravating. So I gave him a physics question, mind you he's had no college physics, it's all from high school. He couldn't solve the problem, but immediately he knew how to attack it. He knew from what angle to start... he knew the concepts without even taking the course.*

EJ11: *Diagrams are easier to read and help with visualization of a whole problem.*

EI12: *By actually looking at that diagram you can visualize [and] have a much better understanding... And I've actually learned how to derive my own formulas.*

EI13: *My TA has been very supportive. He's a wonderful man. In fact that's the only reason I'm actually really getting a good understanding of this because he's just told me exactly where I need to put more effort. And from listening to his advice, I've watched my quiz scores, jump up. And I've watched my own understanding jump up...And plus I've looked back over some of the old quizzes, in fact some of the first quizzes from the semester that I didn't do so well on. I've looked at those and I've realize that if I would have drawn a diagram first I would not have missed some of the things I've missed... You know just stupid mistakes just because I was just throwing in a formula in there. You can't do that.*

FJ9: *Different problems need new different methods.*

FI10: *[In the future], I won't have to remember physics to do it because they'll probably have a calculation on the computer that'll tell me... All I got to do is plug in numbers.*

FJ11: *Some times through trial and error I find my solution, other times I follow extensive directions.*

FJ12: *I never draw diagrams unless told to because I don't see things through diagrams.*

FI13: *I never thought of [drawing diagrams] as being a way to solve problems.*

FJ14: *It seems logical to substitute numbers for formulas and forget the diagrams.*

FJ15: *That seems to be the fastest way to a solution.*

FJ16: *Physics are principles that are tuned into equations and formulas.*

FJ17: *Just look at the wall, at all the formulas.*

FJ18: *Physics is just too much. There are too many formulas.*

Figure 8. Excerpts from student comments on physics methodology.
(See Fig. 6 for explanation)

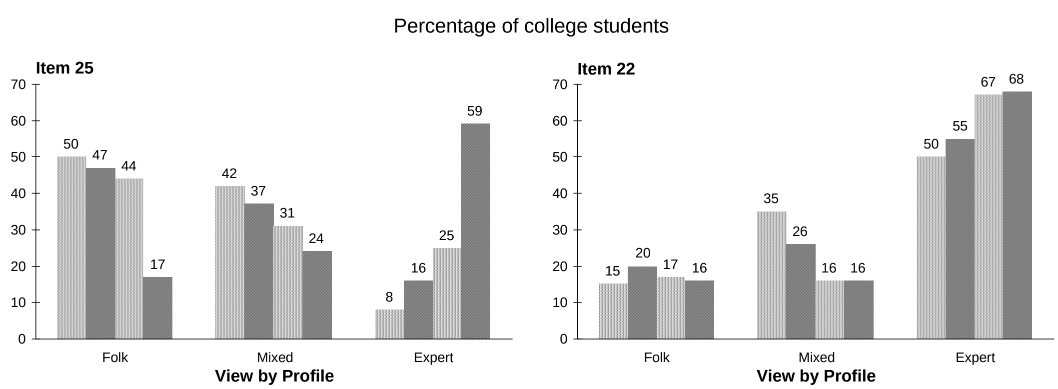
3. Validity

Students often learn physics by rote and do not attempt to analyze information presented to them in physics courses, as will be discussed in the section on *reflective thinking* below. They seldom develop methods for checking their own methods of solving physics problems, and then have little appreciation for error analysis in experimental design (Arons 1984, 1993; Gunstone 1991; Reif & Larkin 1991; Viennot 1985). Such behavior is supported by student views about the validity of scientific knowledge.

The VASS validity dimension probes certain views about the verity and fidelity of scientific knowledge. Figure 9 shows the distribution by profile of student views on two VASS validity items. Item 25 pertains to *refutability* while item 22 pertains to *fidelity* of scientific knowledge. The proportion of student responses consistent with the expert view that scientific knowledge is refutable ranges precipitously from 59% in the EP group to 8% in the FP group (Item 25). The contrast between group responses is not so sharp for item 22 with half the students or more in all profile groups concurring with the expert view that scientific knowledge is approximate.

Comments of EP students in Figure 10 reveal that their beliefs about the limitations of scientific knowledge are rooted in broader metaphysical views about any type of human knowledge. For these students, scientific knowledge is always be *partial* (EJ14) and, being a human product, will always be subject to *error* (EJ15). They believe further that scientific knowledge is subject to *continuous refinement*: (a) by applying current knowledge in its defined domain (EJ16) or in new domains to discover its limitations (EJ17), (b) by making new discoveries (EJ18), or (c) by improving accuracy (EJ19) or efficiency (EJ20). Some EP students have learned that the history of science provides ample evidence for this refinement process (EJ21). Some EP students hold *instrumentalist* views about science, maintaining that the validity of scientific knowledge is a function of its utility and not its actual correspondence to the real world, so the *evolution* of scientific knowledge is not necessarily revolutionary (EI22).

Comments of FP students were not as sophisticated as those of EP students. Most FP students believe that scientific knowledge is absolute and final, often with a blind faith in the capacity of physicists (FJ19) or the honesty of the scientific community (FI20). A few FP students believe that science, like religion, is dogmatic to the extreme of being unquestionable (FI21).



25. Physicists' current ideas about the particles making up the atom:
    (a) will always be maintained as they are.
    (b) could eventually be replaced by other ideas.

22. The laws of physics portray the real world:
    (a) exactly the way it is.
    (b) by approximation.

Figure 9. Profile distribution across student views about two validity items.

EJ14: *We can never know everything about an object.*

EJ15: *Physicists are just like everyone else. They too can be wrong.*

EJ16: *Every time you use a law it is being tested. There might be something else going on that we do not know about.*

EJ17: *The more we learn and the more exceptions in the rules we will find.*

EJ18: *Sometimes a new discovery is made that changes the picture.*

EJ19: *Physicists must often change current ideas when they conceive of a more accurate one.*

EJ20: *Knowledge can be rejected at any time if a better solution is discovered.*

EJ21: *I remember learning about atom structures and all those theories about how atom electrons work. Once someone else had a better idea, the atomic model changed.*

EI22: *We accept things if they seem to give us an advantage. An advantage doesn't mean it's right or wrong, it's just the way we view it... And if it works for us then we use it... if things are working for us now, unless things dramatically in the physical world changed, I don't see, I mean even if we came up with a unified theory, you could still neglect that unified theory and still solve, and have answers, solutions with the current knowledge. I can't imagine. Maybe they'd be better represented in the future to the point where the expressions the way we use them now are not useful.*

FJ19: *If a physicist is describing an object, you would think he would know exactly what it is.*

FI20: *[In physics as in history], it's one idea passed down [from one generation to another]. Usually the ideas in physics aren't manipulated that much by each person it's passed down to. In history it's always a little bigotry you know, say, in civil war era the North was right. So, in a certain textbook in the North, the North will be good guys and then in another text book in the South, the South would be the good guys. In a physics textbook you don't usually see that. You see the same equation being passed down. So we're using the same basic knowledge Copernicus and Galileo presented all that time ago.*

FI21: *[Physics consists of] a set of ideas that are kind of like accepted as fact and kind of like taboo. It's like taboo to go against. They would be accepted over evidence in the real world.*

Figure 10. Excerpts from student comments related to the validity of scientific knowledge.

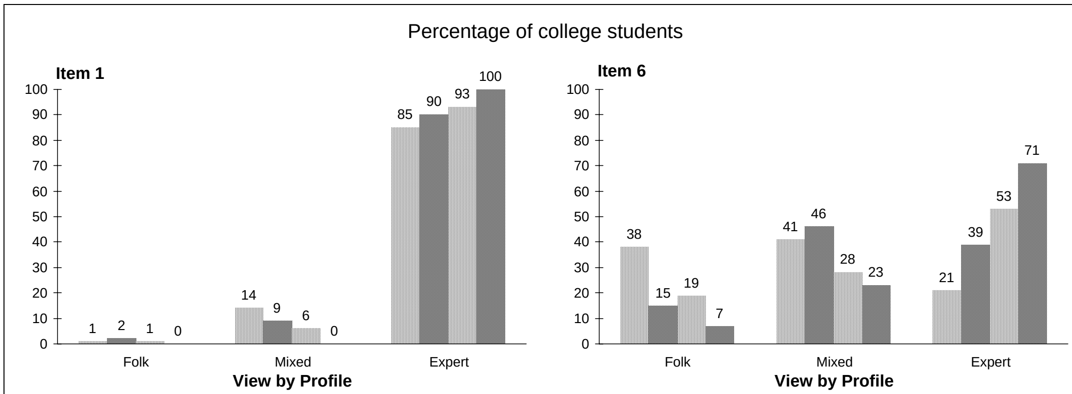
4. Learnability

Physics is among the least favored subject matters for students. Only 24% of high school graduates in the USA had taken physics courses in 1993 (AIP 1996). Rarely a college student takes physics if not required to do so. Moreover, physics courses suffer from attrition rates as high as 40%, and from overall low achievement (AIP 1996; NCEE 1983; NCES 1994; NSB 1993; Tobias 1990). VASS suggests that student views about the learnability of physics may contribute to these problems.

The VASS learnability dimension ranks contrasting views about what it takes to learn science. Figure 11 shows college student responses on two items in VASS's learnability dimension. Item 1 shows that the overwhelming majority of students who take physics hold the expert view that learning physics requires more effort than talent. However, item 6 shows that the percentage expressing the expert view that success in physics depends more on *personal* effort than teacher instruction drops from 71% in the EP group to 21% in the FP group.

Student comments shown in Figure 12 reveal that students with an expert profile believe that learning physics is foremost a matter of personal attitude (EJ23, EJ24). Commitment is required to learn anything, though learning physics is easier for some than others (EJ25). Sometimes old habits of mind must be revised (EJ26).

In contrast, students with a folk profile have *authority-dependent* views of learning. Even those who recognize the importance of personal effort believe that what they learn depends primarily on the teacher (FJ22). Once they get used to a given teaching style, some FP students have a hard time adjusting to a different style (FJ23). Some FP students believe that learning physics requires skills that 'ordinary people' do not possess (FJ24), are not willing to develop (FJ25), or cannot develop because of a gender gap (FJ26).



1. Learning physics requires:
   (a) a serious effort.
   (b) a special talent.

6. For me, doing well in physics courses depends on:
   (a) how much effort I put into studying.
   (b) how well the teacher explains things in class.

Figure 11. Profile distribution across student views about two learnability items.

EJ23: *I feel it depends on the attitude you take toward the subject.*	FJ22: *Depending on who teaches the course, how they teach it, and how long they give the students to comprehend it all.*
EJ24: *I am an ordinary person and my friend is gifted. We are both enrolled and passing physics.*	FJ23: *In the past, physics was fun and challenging. Now it is difficult and I feel that the professor is not explaining what we are doing correctly. He tries to make it hard.*
EJ25: *Anyone can learn anything they want to. Just some may understand faster than others.*	FJ24: *A degree of visualization is required that ordinary people don't have as much.*
	FJ25: *I feel that most ordinary people don't have the will power to learn physics, so they generally can't.*
EJ26: *Some concepts are hard to accept at first because of what we were taught when we were kids, but once you get over that, it is pretty easy.*	FI26: *I'm not really used to thinking in terms, mechanically...I think guys are used to building cars, or helping their dad with the cars. I never had any exposure to any of that kind of stuff.*

Figure 12. Excerpts from student comments on the learnability of physics.

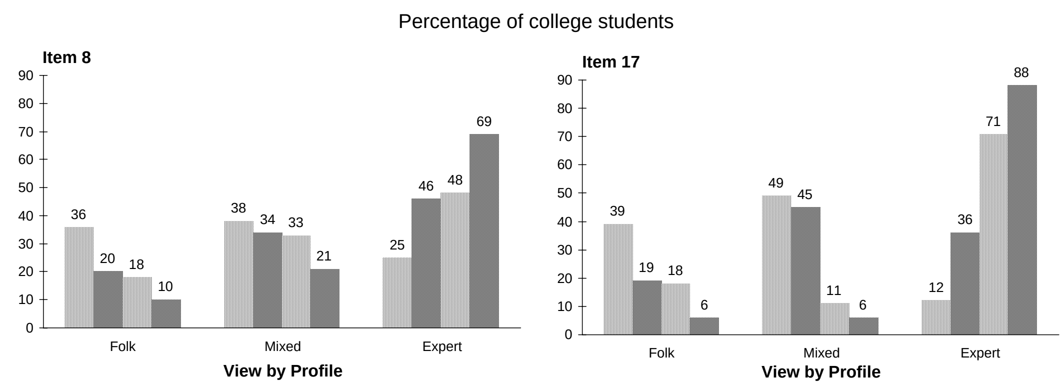
5. Reflective thinking

High school and college students often bring to their physics courses a rich array of beliefs about the physical world that are incompatible with scientific theory. These beliefs are not significantly affected by traditional physics instruction and contribute to students' low achievement (Halloun & Hestenes 1985-a & b; Hestenes *et al.* 1992; Reif 1987; Reif & Larkin 1991; Van Heuvelen 1991). VASS suggests that students have little appreciation of reflective thinking, which may contribute to their failure to resolve incompatibilities between their initial knowledge and scientific theory.

VASS does not evaluate thinking abilities. Rather, it ranks beliefs about important factors in reflective thinking (Fig. 1). Figure 13 shows the distribution of student responses by profile on two items in the VASS reflective thinking dimension. Item 8 shows that the fraction of students who follow the expert practice of *reconstruction* drops from 69% in the EP group to 25% in the FP group. A sharper drop from 88% in the EP group to 12% in the FP group is observed in item 17, concerning the expert preference for *self-regulation* over mimicking the teacher.

As shown by comments in Figure 14, students with an expert profile realize that one cannot understand physics through rote learning (EJ27) for various reasons. Their arguments ranged from reference to the amount of information involved (EJ28) to the belief that meaningful understanding requires one to structure information coherently (EJ29). They argued that new knowledge must be framed within a well-defined scientific theory (EI30), compared to, and integrated with, prior knowledge (EI31 and EJ32), using one's own conceptual tools (EJ33). This makes new information easier to remember (EI31 and EJ32). Mistakes are regarded by EP students not as stumbling blocks but as stepping stones towards more beneficial knowledge (EJ34).

In contrast, students with a folk profile resort to sheer memorization of physics formulas even when they know that this is not the road to meaningful understanding (FJ27 and FI28 in Fig. 14). Some see nothing in physics but confusing mathematical symbolism to be memorized by rote (FI29 and FJ30). Others argue that teaching (FI28) and testing (FJ31 and FJ32) in physics courses drive them in the rote direction. FP students often feel more comfortable mimicking their teachers either because they fear getting lost on their own (FI33 and FJ34) or because they see the classroom environment as not conducive of reflective thinking (FJ35).



8. When studying physics in a textbook or in course materials:
   (a) I find the important information and memorize it the way it is presented.
   (b) I organize the material in my own way so that I can understand it.

17. After the teacher solves a physics problem for which I got a wrong solution:
   (a) I discard my solution and learn the one presented by the teacher.
   (b) I try to figure out how the teacher's solution differs from mine.

Figure 13. Profile distribution across student views about two reflective thinking items.

EJ27: *By memorizing a person will not understand the concepts of physics.*

EJ28: *You cannot memorize information in physics. It's too much.*

EJ29: *I don't like to stack bricks together, but melt them into one if I can.*

EI30: *There's nothing I've learned in physics that I haven't rederived by myself... Normally I don't use the books approach...I would like there to be a greater opportunity to go through the background of every topic and explain how theories were used to get modern equations and where the theories came from and sometimes what observations were made to get to the theories and how to use what we know for things that seem to be exceptions to the rules.*

EI31: *I don't like to flat out memorize stuff. Through my own experience memorizing stuff I tend not to retain it as long in memory as if I actually apply it to something or find some way to link it in. Memorizing just doesn't stay up there. I like to have information linked to some use.*

EJ32: *It's easier to remember something if you can compare it to something you've already learned.*

EJ33: *Formulas, experiments and laws don't fascinate me. I like to see a picture of the info in my head.*

EJ34: *I find it more benefiting to learn from mistakes.*

FJ27: *I can't derive every physics principle, so much info is just memorized. But deriving the major laws gives a better understanding.*

FI28: *You need to get your grade. A lot of people think about grades in Physics. By memorizing the relevant information in the text book or my class notes, it will be easier to recall... on the test. I think... the ideal way should be... by reconstructing, but I think [memorization] is really stressed in the classroom.*

FI29: *Sometimes it's really confusing to decipher between like what 'j' is, and 'y', 'x' and distance and the difference between all these different numbers and letters... they use the same character...like 'd' [for distance] would also mean the differential.*

FJ 30: *Physics is just like math. You just have to memorize and know how to use various formulas.*

FJ31: *Tests and grades depend on memorizing the uses of the equations.*

FJ32: *Tests check one's knowledge more than one's thinking ability.*

FI33: *I don't take to this stuff as easy as other people... I just try to keep it in the classroom, and I try to understand as much as I can without going beyond that, because I'm afraid I'll screw everything up and I won't understand it any more.*

FJ34: *You don't want to move too far away from a teacher's style or you will get lost.*

FJ35: *This class is not oriented toward open thinking.*

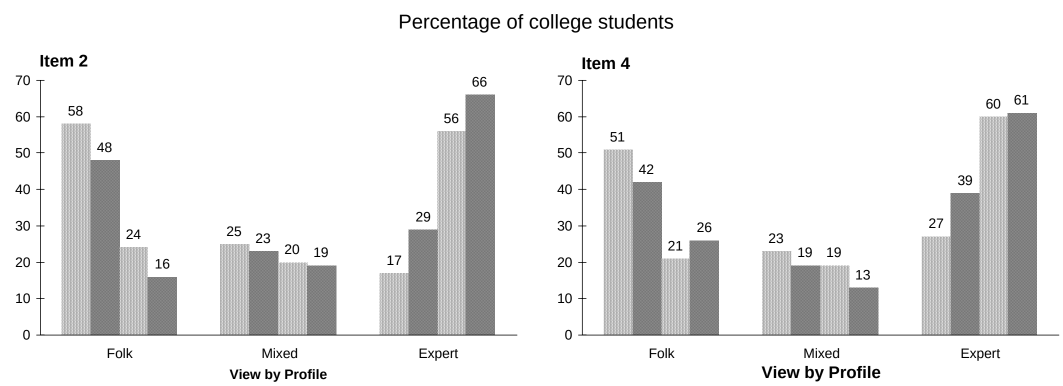
Figure 14. Excerpts from student comments related to reflective thinking.

6. Personal relevance

It takes commitment to learn physics, and VASS probes the dependence of this commitment on the perceived personal relevance of science. Figure 15 shows the distribution of student responses on two items in the personal relevance dimension of VASS. Item 2 shows that the fraction of students strongly motivated to take physics drops from 66% in the EP group to 17% in the FP group, while item 4 shows that the fraction who see physics as personally beneficial varies from 61% in the EP group to 27% in the FP group.

As shown by the comments in Figure 16, students with an expert profile see the personal value of physics as depending on its recognized relevance (EJ35). They argue that physics is relevant to everyone, because of the generic nature of its conceptual tools (EJ36 and EJ37) and the utility of the factual information it provides about the universe (EJ38 and EJ39). Some EP students see knowledge as intrinsically valuable (EJ40), while others have a strictly utilitarian view of its value (EJ41).

In contrast, the comments in Figure 16 of students with a folk profile reveal three levels of disinterest in physics. Some FP students recognize the relevance of physics to the physical world, but not its utility in everyday life (FJ36 and FJ37). A second group of FP students see no value whatsoever in physics (FJ38), either in their education (FJ39), or in their workplace (FJ40). For some this is because the world of physics is ideal and dissociated from the real world (FJ7 and FJ8 in Fig. 6 above). A third group has lost interest in physics because of repeated frustration and failure (FJ41 in Fig. 16).



2. If I had a choice:
   (a) I would never take any physics course.
   (b) I would still take physics for my own benefit.

4. I study physics:
   (a) to satisfy course requirements.
   (b) to learn useful knowledge.

Figure 15. Profile distribution across student views about two personal relevance items.

EJ35: *People have the capacity to learn and understand anything, but when people don't see its relevancy then they often disregard its importance and when they fail the first time it gets them down.*

EJ36: *Physics is a set of tools. Tools can be used for anything.*

EJ37: *I like applying the physics I know to everyday situations, I've been able to assimilate it into my logic process.*

EJ38: *Physics is very interesting and is a part of everyday life. It is necessary to know your surrounding's function.*

EJ39: *Understanding the world makes it easier to live in.*

EJ40: *You always improve your life when you learn something new. It gives you a new way to see and understand things.*

EJ41: *If I do well I will make gobs of money.*

FJ36: *Many people intuitively understand physics, pool players for example, but that is far from formal theory. Furthermore, knowing how to precisely calculate a collision won't help me be a better pool player.*

FJ37: *Physics helps in real life situations more subconsciously than consciously. I had a high school physics teacher who claimed that knowing the laws of momentum saved him from an automobile accident.*

FJ38: *I don't see much use for the information, and I'm not interested in and do not desire to do more work.*

FJ39: *I don't see how it relates to my major.*

FJ40: *Who needs physics if that person is working per se at McDonald's? I worked there over the summer and I didn't need it.*

FJ41: *For reasons unknown, I lost interest in physics. The frustration at having to force myself to so something I do not want to, and failing at it, is too much.*

Figure 16. Excerpts from student comments related to personal relevance of physics.

Discussion

Characteristics of the four profiles (Fig. 4) have been analyzed above along each of the six VASS dimensions (Fig. 1). Now we compress the analysis into broad characterizations across the scientific and cognitive domains separately. Then we discuss how views in these domains are interrelated in VASS profiles. Finally, we discuss the relation of VASS profiles to student achievement in physics.

To systematize student views within the two broad domains, we have defined a set of four subprofiles within each domain in the manner described in Table 1 for the entire VASS instrument. Procedural details of domain classification are given elsewhere (Halloun *et al.*, 1997). Here we concentrate our discussion on the characteristics of expert and folk subprofiles within each domain.

Our analysis of VASS results necessarily touches on deep philosophical issues about the nature of science and cognition, but it ignores many philosophical subtleties in order to capture *broad tendencies* in philosophical viewpoints. In particular, our overall classification of VASS results into profiles aims to distinguish a prototypical expert (scientific) viewpoint from a prototypical folk (unscientific) viewpoint. Experts sometimes choose folk responses to individual VASS items for good reasons which VASS is not designed to detect. However, the expert profile is defined broadly enough to encompass such differences of opinion within the expert camp. Our interviews of students show that those with folk profiles seldom have well considered reasons for their choices on individual VASS items, whereas those with expert profiles often exhibit considerable insight in their justifications. The folk views are generally more heterogeneous than the expert views. Some opinions expressed in the interviews are not so much expressing a philosophical perspective as an indictment of the teaching encountered.

In the following we use terms like 'scientific realism' loosely, to indicate broad philosophical perspectives. We are not concerned with the technical definitions needed to articulate a sharp philosophical position. Our meanings for such terms should be sufficiently clear from the context.

Scientific dimensions

Research on student views about the nature of scientific knowledge has produced conflicting results. Edmondson and Novak (1993) reported that the 'majority of college students hold essentially positivist views [that knowledge] is discovered through observation, unfettered by previous ideas or beliefs', and that scientific knowledge consists of 'separate, objective truths that are domain-specific and constant'. However, Aikenhead (1987) found that only 25% to 36% of Canadian high school graduates hold such positivist views, while 45% recognize scientific knowledge as a human construction and a partial representation of reality. Aikenhead also reported that while 'almost all students would seem to agree that scientific knowledge is tentative, but ... in different and often conflicting ways', 44% believed that this knowledge may be subject to change, and 31% believed that it may not. Songer and Linn (1991) classified middle school students' views of science 'into three groups: static, mixed, and dynamic. Those who view science as static [21%] assert that science consists of a group of facts that are best memorized. Those who view science as dynamic [15%] believe that scientific ideas develop and change... Students with mixed beliefs [63%] hold some static and some dynamic views'. Though not completely in agreement, VASS results are closer to the findings of Aikenhead and especially of Songer and Linn than to those of Edmondson and Novak.

Along the scientific dimensions (Fig. 1) VASS results over a period of three years have consistently shown that no more than 20% of college students and 25% of high school students have views indicative of *positivism* or *naive realism*, while about 20% hold opposing views consistent with *scientific realism*. The remaining 55 to 60% of students hold admixtures of both types of views. Most naive realists have folk profiles. Virtually all students with an expert profile and a fraction of students with a transitional profile (mostly one third of HTP students) are essentially scientific realists.

Naive realists believe that the physical world is exposed directly to our senses and that scientific knowledge mirrors this reality. Consequently, they often believe that scientific knowledge is exact, absolute and final, as well as situation-specific, piecemeal, and developed from arbitrary rules of thumb. Naive realists often believe that physics is guided by mathematical rules for manipulating formulas.

In contrast, scientific realists believe the physical world cannot be known directly through sense perception, but only indirectly through theoretical constructions. Consequently, they believe that scientific knowledge is approximate, tentative and refutable, as well as generic, coherent and systematically structured and applied.

Cognitive dimensions

There is, of course, an enormous literature pertaining to each of the cognitive dimensions probed by VASS (Fig. 1). Here is a sampling of relevant work:

- Arons (1984), Reif (1987), and Reif and Larkin (1991) discuss the widespread belief among students that physics can be learned by memorizing factual knowledge and formulas piecemeal.
- Analyzing the discourse of college students about physical phenomena, Cobern (1993) found that 'most students assigned science a minor role in their lives', noting that 'what was most striking about the interview texts was the conspicuous absence of scientific talk, although these students had successfully completed several college science courses and were majors in a science-related field'.
- In a national survey conducted by the National Science Board, only 52% of 17-year old high school students considered that 'most of what [they] learn in science classes is useful in everyday life' (NSB 1993).
- In independent studies with junior high school students, Simpson and Oliver (1985) and Baker and Piburn (1991) found that student attitudes toward science declined significantly following science instruction. Ebenezer and Zoller (1993) reported that, although 73% of students 'feel the study of science in school is important', only 38% 'would like to study more science'.

VASS results in the cognitive dimensions (Fig. 1) show that, when it comes to learning physics, about 28% of college students and 22% of high school students can be characterized as *passive learners*, while 14% of both groups are *critical learners.* The remaining students hold mixed cognitive views. Most passive learners have folk profiles (Fig. 4). Virtually all students with an expert profile are critical learners, as are about one fifth of the students with high transitional profiles.

Passive learners are authority-dependent, believing that their understanding of physics depends more on instruction than personal effort. They tend to concentrate on isolated facts and formulas in physics, memorizing them by rote without relating them to prior knowledge. They see little relevance of physics to everyday life, and so their concern with physics is limited to satisfying course requirements.

In contrast, critical learners are authority-independent, believing that their understanding of physics depends more on personal effort than instruction. They tend to concentrate more on reasoning processes than factual information in physics. They are reflective thinkers, seeking a coherent understanding of physics, striving to detect and resolve discrepancies between accepted scientific knowledge and their own. Critical learners see physics as relevant to everyday life, so they pursue the study of physics more for personal benefit than for fulfilling curriculum requirements.

Relation between scientific and cognitive dimensions

Many researchers have argued that student beliefs about the nature of scientific knowledge are coupled to their learning styles (Edmonson & Novak 1993; Hammer 1994; Reif & Larkin 1991; Songer & Linn 1991; Tobias 1990). VASS results support this conclusion.

Analysis of crosstabulation between the four subprofiles within the scientific domain and those within the cognitive domain resulted in a Chi-Square value of 254 (p=.000). This shows that students' views about the nature of physics are significantly related to their views about learning physics. Thus, a naive realist is likely to be a passive learner, and a scientific realist is likely to be a critical learner. In fact, an Odds Ratio analysis between the extreme profiles revealed that the likelihood of a naive realist being a passive learner or a scientific realist being a critical learner is about 22 times the likelihood of a naive realist being a critical learner or a scientific realist being a passive learner.

VASS Profiles and Achievement

It has often been argued that students' views about knowing and learning science are major determinants of their achievement in science courses (Baker & Piburn 1991; Reif & Larkin 1991; Schibeci & Riley 1986; Songer & Linn 1991; Tobias 1990). VASS results support this view.

The relation of VASS profiles to achievement in physics courses has been assessed by comparing the profiles with final grades and performance on the *Force Concept Inventory* (FCI), an instrument for assessing qualitative understanding of Newtonian mechanics (Hestenes, Wells & Swackhamer 1992). Details are given elsewhere (Halloun 1996), but one relevant result is presented in Figure 17 showing how FCI gain varies across the four VASS pretest profiles.

The gain factor *g* used in Figure 17 is defined for every student as the ratio of the actual pretest-posttest gain on the FCI to the maximum possible gain. In a comparison of about six thousand high school and college students nationwide, Hake (1996) found an average gain factor of .23 in courses where physics is taught by traditional lecture–demonstration methods, compared with .52 for courses taught by methods which engage students actively in collaborative tasks. The data in Figure 17 come from a population of 1568 students from 39 high schools across the USA, in 30 of which the physics teaching is more traditional than interactive. Figure 17 shows that 65% of the students who start their physics course with a VASS expert profile achieve high gains on the FCI (greater or equal to .52), while 45% of the students with a VASS folk profile achieve low gains on the FCI (below .23). The figure shows a clear ranking correlation of FCI gain with VASS pretest profiles. Similar correlation between VASS profiles and course grades have been

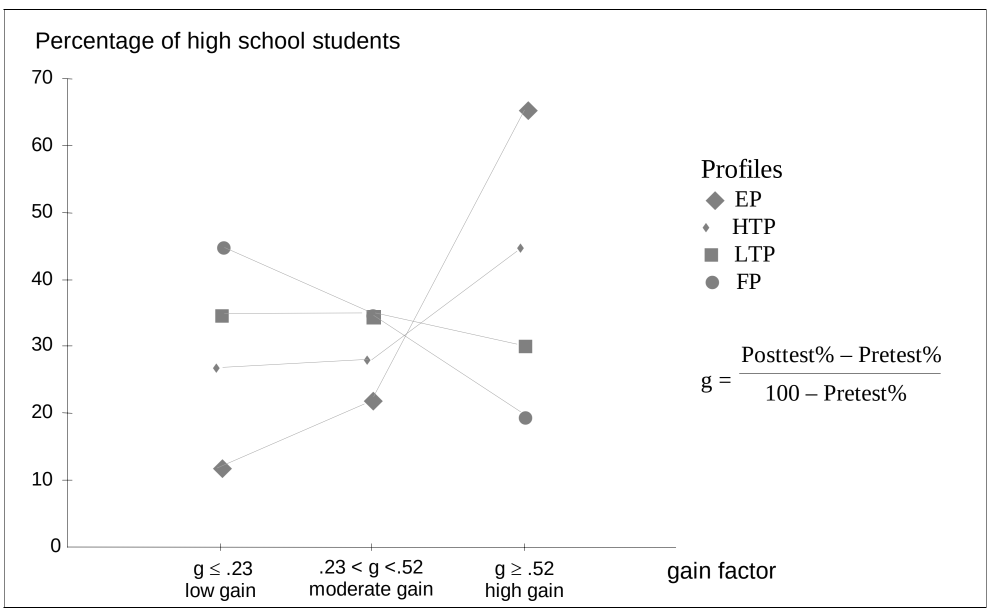


Figure 17. Distribution of high school physics student VASS pretest profiles across FCI gains.

found for both college and high school (Halloun 1996; Halloun & Hestenes 1997). Such correlations suggest that *student views about knowing and learning physics may be major determinants of achievement in physics courses*.

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