DOCUMENT RESUME

ED 394 840 SE 058 338

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TITLE	Views About Sciences Survey: VASS.
PUB DATE	1 Apr 96
NOTE	32p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (St. Louis, MO, March 31-April 3, 1996).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Higher Education; *Science Education; Sciences; Secondary Education; *Student Attitudes; Surveys

ABSTRACT

The Views About Sciences Survey (VASS) is a survey of student views about science for the purpose of assessing the influence of these views on learning. This paper discusses the survey's design, development, results, and implications for science education. The survey assesses student views along seven dimensions with a novel Contrasting Alternatives Design. It was administered in 23 states to about 8,000 high school and college students enrolled in physics, chemistry, and biology courses. Results indicate that students at all levels hold views about knowing and learning science that often diverge from the views of scientists and educators, student views differ according to discipline and across some demographic strata, and student views are hardly affected by traditional science instruction, but they affect what students learn in the course of such instruction. Contains 72 references. (Author)

Views About Sciences Survey

VASS

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Abstract

VASS is a survey of student views about science for the purpose of assessing the influence of these views on learning. This paper discusses the survey's design, development, results and implications for science education. Student views are assessed along seven dimensions with a novel Contrasting Alternatives Design. In the last two years, VASS has been administered in 23 states to about 8,000 high school and college students enrolled in physics, chemistry and biology courses. Results show that: (a) students at all levels hold views about knowing and learning science that often diverge from the views of scientists and educators, (b) student views differ according to discipline and across some demographic strata, (c) student views are hardly affected by traditional science instruction, but (d) they affect what students learn in the course of such instruction.

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NARST Annual Meeting
April 1st, 1996
St. Louis, Missouri

Educational researchers have observed that students at all levels are encumbered with *folk* views about the nature of science and science education that are incompatible with the views of scientists and educators. Introductory science courses do little to change student folk views and, more often than not, the changes are negative. Furthermore, students' achievement in science courses may be negatively affected by their folk views (Aikenhead et al., 1987, 1988; Baker & Piburn, 1991; Cobern, 1993; Edmonson & Novak, 1993; Redish & Saul, 1995; Schibeci & Riley, 1986; Songer & Linn, 1991).

We have developed the *Views About Sciences Survey* (VASS) to explore and systematize such observations, and we have administered it to thousands of high school and college students across the USA. This paper discusses the survey's design, development, and results.

Objectives

VASS has been developed to survey student views about *knowing* and *learning* science and to assess their *relation to student understanding* of science. More specifically, VASS is designed to meet the following objectives:

1. To ascertain significant *differences* between the views of students, teachers and scientists.
2. To identify patterns in student views and classify them in general *profiles*.
3. To measure the *effectiveness of instruction* in *changing* student views and profiles.
4. To compare student views/profiles at various grade levels (8-16).
5. To assess the relation between student views/profiles and achievement.
6. To ascertain differences in the views/profiles of students in the various sciences (physics, chemistry, biology,...).
7. To compare student views/profiles across various demographic strata.

Taxonomy

To identify major issues that should be addressed by VASS, we reviewed related works in the relevant literature, including the following:

1. Scholarly views on the epistemology of science (e.g., Bernard, 1865; Bunge, 1973; Giere, 1988; Harre, 1959; Johnson-Laird, 1983; Kuhn, 1970; Lakatos & Musgrave, 1974; Lakoff, 1986; Lecourt, 1974; Popper, 1983; Tobin, 1993; Ullmo, 1969).
2. Major works in cognition (e.g., Changeux, 1983; Dewey, 1933; Ericsson & Charness, 1994; Gardner, 1985; Gilovich, 1991; Ginsburg & Opper, 1979; Glass, Holyoak & Santa, 1979; Grossberg, 1982; Jones, 1986; Klahr, 1976; Lochhead & Clement, 1979; Margolis, 1987; Newell & Simon, 1972; Perry, 1970; Piaget, 1972; Resnick, 1989; Simon, 1979; Squire, 1986; Stewart, 1985; Tobin, 1993)
3. National science standards (AAAS, 1990 & 1993; NCEE, 1983; NRC, 1996; NSTA, 1993 & 1995).
4. Research on student views about science (e.g., Aikenhead et al., 1987, 1988; Baker & Piburn, 1991; Barrington & Hendricks, 1988; Cobern, 1993; Cooley & Klopfer, 1961; Ebenezer & Zoller, 1993; Edmonson & Novak, 1993; Germann, 1988; Gilbert, 1991; Kimball, 1968; Klopfer, 1969; Lederman & O'Malley, 1990; Mackay, 1971; Meichtry, 1993; Redish & Saul, 1995; Roth & Rychoudhury, 1993; Rubba & Andersen, 1978;

Schibeci & Riley, 1986; Schmidt, 1967; Simpson & Oliver, 1985; Songer & Linn, 1991; Welch & Pella, 1967).

In constructing a taxonomy of the issues we identified, we sought to avoid: (a) arcane and problematic questions about the epistemology of science, and (b) bias toward our own position (Halloun, 1996–a & b; Hestenes, 1992). We devised one VASS instrument after another to assess student views on the targeted issues, and we kept refining our taxonomy and the VASS items based on:

1. Peer review.
2. Students' answers on VASS items (as well as teachers'), and their relation to course achievement and performance on content-based conceptual surveys like the Force Concept Inventory (Hestenes et al., 1992).
3. Interviews with respondents.

We finally settled on four epistemological dimensions and three pedagogical dimensions. The epistemological dimensions pertain to the structure and validity of scientific knowledge, scientific methodology, and role of mathematics in science. The pedagogical dimensions pertain to learnability of science, critical thinking, and personal relevance of science. To assess variability in student views in different disciplines, we constructed parallel forms of VASS along these dimensions for physics, chemistry and biology.

Each of the seven dimensions is framed below in the form of pairs of contrasting views about science or science education that our analysis revealed to be the most prevalent. The primary view, hereafter referred to as the *expert* view, is the one we found to be most common among scientists and educators. The opposing view, hereafter referred to as the *folk* view, is often held by the lay community and science students at all grade levels.

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.

3. ***Validity:*** Scientific knowledge is *approximate, tentative,* and *refutable*
   — rather than exact, absolute and final.

4. ***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.

5. ***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.

6. ***Critical 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.

7. ***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 just fulfilling curriculum requirements.

VASS with Contrasting Alternatives

Traditional assessment instruments present items in one of two formats: (a) open– (or constructed–) response, or (b) objective– (or selected–) response. Open formats like interviews and essays can be valuable and informative means of assessment for purposes like ours. However, they are not feasible for large populations. Objective formats like multiple-choice and Likert scale are more practical and cost-efficient. However, research indicates that they encounter insuperable validity and reliability problems when used in surveying students' views about science (Halloun, 1994; Krynowsky, 1988; Munby, 1983; Rennie & Parker, 1987; Symington & Spurling, 1990).

For VASS, we needed a valid and reliable testing format that could be used to survey large populations efficiently. Since no traditional format meets all three criteria: validity, reliability and feasibility, we devised a new item format that requires respondents to balance between two contrasting alternatives. We kept refining our items until we were satisfied that we have an instrument meeting all three criteria.

Figure 1 shows one pedagogical item and one epistemological item from VASS Form P11 for physics. Each item consists of a statement followed by two contrasting alternatives which respondents are asked to balance on an eight-point scale. 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 one (option 8). Advantages of the *Contrasting Alternatives Design* (CAD) and other features of VASS are discussed below.

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

The laws of physics are:
(a) inherent in the nature of things and independent of how humans think.
(b) invented by physicists to organize their knowledge about the natural world.

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 1: Sample CAD items from VASS Form P11.

Validity

1. Content issues

People have difficulty thinking about any issue in the abstract. It is always easier to think within the context of a familiar situation, and the narrower the context the better. Contrary to common practice in the design of traditional instruments for assessing student views about science, VASS: (a) asks questions about specific disciplines, (b) narrows issues in a given question down to a single factor in a given dimension, and (c) is restricted to issues that are within the scope of target populations.

As a rule, surveys that we have examined ask questions about "science" in general. We suspected that student opinions would differ according to discipline, so we designed different VASS forms for different disciplines (biology, chemistry and physics, so far), but preserving the seven dimensions of our taxonomy.

Student views about science vary not only between disciplines, but also within a discipline. Student epistemological views often vary from one theory to another within the same science or even from one law to another within the same theory. Where appropriate, VASS accounts for students' sensitivity to content by asking the same question in more than one context within the same science. In this regard, Figure 2 gives examples of different ways to ask a question.

Traditional instruments often address several factors in a single question (Fig. 3). In VASS, each question concentrates on a single factor within a given dimension as can be seen in Figures 1 and 2, and as it will become more evident in the course of our discussion.

Traditional instruments also often address issues that are beyond students' purview and experience (The test called TOUS in Figure 3 has been administered to fifth graders!). Such questions have little utility, and are thus avoided in VASS.

Science Process Inventory - Form C (Welch & Pella, 1967):

Once a statement of science becomes a law of science, it will not be changed. *(Agree / Disagree).*

Nature of Scientific Knowledge Scale (Rubba & Andersen, 1978):

Today's scientific laws, theories, and concepts may have to be changed in the face of new evidence. *(Likert Scale)*

VASS – Form P11:

Newton's laws of motion:
- (a) will always be used as they are by physicists.
- (b) will eventually be replaced by other laws.

Physicists' current ideas about the types of particles making up the atom:
- (a) will always be maintained by physicists.
- (b) will eventually be replaced by other ideas.

Figure 2: VASS asks about the falsifiability of science in specific contexts rather than in the abstract as in traditional instruments.

Test Of Understanding of Science (Cooley and Klopfer, 1961):

A scientific theory should:

A. provide the final solution to scientific problems.

B. suggest directions for making useful things.

C*. tie together and explain many natural events.

D. suggest good rules for carrying out experiments.

* considered as "best response" by the authors of TOUS.

Germann (1988):

Science makes me feel uncomfortable, restless, irritable, and impatient. *(Likert scale)*

Figure 3: Sample traditional questions addressing many factors in each question.

2. Interpretation

Popular test formats such as the Likert scale are often open to a wide variety of interpretations by respondents as well as by researchers. Two respondents may express opposite positions on a Likert item for the same reason, or the same position for contradictory reasons (Aikenhead, 1988). When presented in a CAD format, respondents are focused on the context within which they need to answer a given question, and so are researchers in interpreting responses.

Essay and Likert questions can be misleading, especially when students' priorities or value judgments are not the same as researchers', which is often the case. When VASS was first administered in essay format, students were asked in one of the questions to state the first thing they do in solving a physics problem. The student in Figure 4 replied that he starts by looking for the appropriate *formula*. When interviewed, it became evident that the first thing this student actually does in solving a physics problem is *draw diagrams*, but this procedure seemed so trivial for him that he thought it was not worth mentioning in his written response. Had the question been asked in a Likert format:

The first thing I do when solving a physics problem is to search for formulas that relate givens to unknowns,

this student would have undoubtedly agreed with the statement. Had the same question been asked differently in the same format, such as

The first thing I do when solving a physics problem is to represent the situation with sketches and drawings,

the same student would have also agreed with the statement. Thus, contradictory results would be obtained with two Likert items that are supposedly intended to measure the same thing. CAD rectifies the situation by providing the two contrasting statements and asking students to express their position relative to both (Item 13 in Form P11):

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.

I: Describe what you normally do when solving a physics problem. List all steps you often follow, in order.

S: *First step in any problem would be to read the problem and list what's given and what you need, variables or what not. And the next step would be to find formulas that include these variables. And then, the third would be to solve for the unknowns. That's basically it.*

I: So this would be an algorithm you would work through in any kind of problem?

S: *Basically, I would agree. It's a basic general, general outline of how to solve a problem.*

I: Do you ever consider drawing some kind of a diagram?

S: *Uh-huh... I'd consider that helpful, yeah, I'd probably include that in step one. Draw, label, find out what you have and don't have.*

I: So that becomes then, your first step.

S: *Uh-huh.*

I: Would that be true for any kind of problem?

S: *Visualization helps a lot. I would say it would be a good step to try in any problem. If you can't visualize it, I wouldn't try to draw it. Yeah, I would agree that would have to be helpful for any kind of problem.*

I: Do you usually do it?

S: *Do I do it? Usually yes. It's almost asked of us in physics class: force diagrams, free body diagrams. I would say they're probably most helpful. I would say, yeah.*

Figure 4: Excerpt from an interview with a university physics student.

The content and face validity of VASS were assessed by a number of experts in the field. Where appropriate, items were refined until they were unanimously accepted by reviewers. VASS was also administered to a number of high school and college teachers. The trend in the majority of teachers' responses did not diverge significantly from our taxonomy (details in the Results section).

Interviews with some high school and college students revealed that they understood both the questions and the type of answer. Some confessed that it took a few minutes to grasp the CAD format since they were not familiar with it. But then they all said that the format helped them focus their thinking on the issues at hand. Moreover, they all expressed an understanding of, and a satisfaction with, the eight point scale, especially the distinction between options 2 and 3, and options 5 and 6, which they thought helped them better express their position.

Reliability

1. Internal reliability

Internal reliability of an instrument is traditionally measured with coefficients like Cronbach Alpha or Kuder-Richardson, or with factor analysis. Classical reliability assessment though requires "scoring" items in a way that may not be applicable to VASS. Item Response Theory provides alternative assessment means which in principle do not require traditional scoring. We are currently exploring various alternatives for assessing the internal validity of VASS within the framework of either classical theory and IRT.

2. External reliability

Responses on similar items in the consecutive VASS forms were compared for students enrolled in the same courses at the same institutions. No significant differences were detected in the patterns of students' answers.

Feasibility

VASS is efficient in the sense that its CAD format allows one to assess student views with the least effort possible on the part of both administrators and participants, and with minimal cost.

The VASS format is flexible enough to allow administration in various settings (inside or outside the classroom) and via different means (e.g., paper-and-pencil or electronically). Classroom administration of any VASS form takes 30 minutes at most. As a paper-and-pencil instrument, VASS consists of reusable questionnaires accompanied by scannable double-sided *VASS Answer Sheets* of our own design. Answers are marked on a single answer sheet, and sheets are scanned and data transferred to our computers in a format that allows us to readily process them with any statistical analysis software.

History of VASS

Figure 5 outlines the history of VASS as it evolved over more than two years from an essay type survey to a CAD type. Following a review of major works in the epistemology of science, cognition, national science standards, and educational research related to our work (references in the preceding section), we developed a preliminary taxonomy of expert and folk views about science and learning. The taxonomy was then revised with a number of experts in the field, and an essay-type instrument was devised and administered in December 1993 to a sample of 41 college physics students. Following analysis of student responses on the instrument and interviews with some of the students, separate but parallel open CAD VASS forms were designed for physics, astronomy, chemistry and biology.

In the open CAD format, an item was presented in the form of a statement followed by two contrasting alternatives. Respondents were asked to balance the two positions on a eight-point scale, as in Figure 1. However, when they chose neither alternative (option 8), they had to write their own answer. Furthermore, students had to explain any option they chose in their own words. Two forms of 27 questions each were then developed for each of the four disciplines (physics, astronomy, chemistry and biology). One form addressed issues related to the epistemology of the discipline (dimensions 1 through 4 above, and others); the other, issues related to teaching and learning that discipline (dimensions 5, 6, 7, and others). Moreover, respondents' educational and social backgrounds were documented, as well as their expectations about the courses in which they were enrolled.

The open CAD VASS forms were administered in the spring of 1994 to 754 high school and college students. Following analysis of VASS responses and interviews with some students, the two forms in each discipline were refined (except for astronomy which is still on the back burner), and items were transformed to a CAD format where students were required to balance the two alternatives on the same eight-point scale as before.

However, respondents were not asked to provide their own answer if they were not satisfied with the alternatives, or to justify their answers. They marked their answers on scannable answer sheets of our own design.

The new forms were administered in the 94-95 academic year to 3,490 high school and college students, and evaluated in the same way as their predecessors. Furthermore, the relationship was analyzed between students' responses on VASS on the one hand, and their final grades in their respective courses and, in the case of physics, their performance on a standardized conceptual instrument, the Force Concept Inventory (Hestenes et al., 1992), on the other hand. Consequently, the taxonomy of VASS was refined, and the two forms in each discipline were replaced by a single form of 33 CAD items each. Thus far, the latest VASS forms (P11 for physics, C11 for chemistry, and B11 for biology) have been administered in the 95-96 academic year to 3,686 high school and college students enrolled in 44 institutions (4 of which are universities) in 23 states.

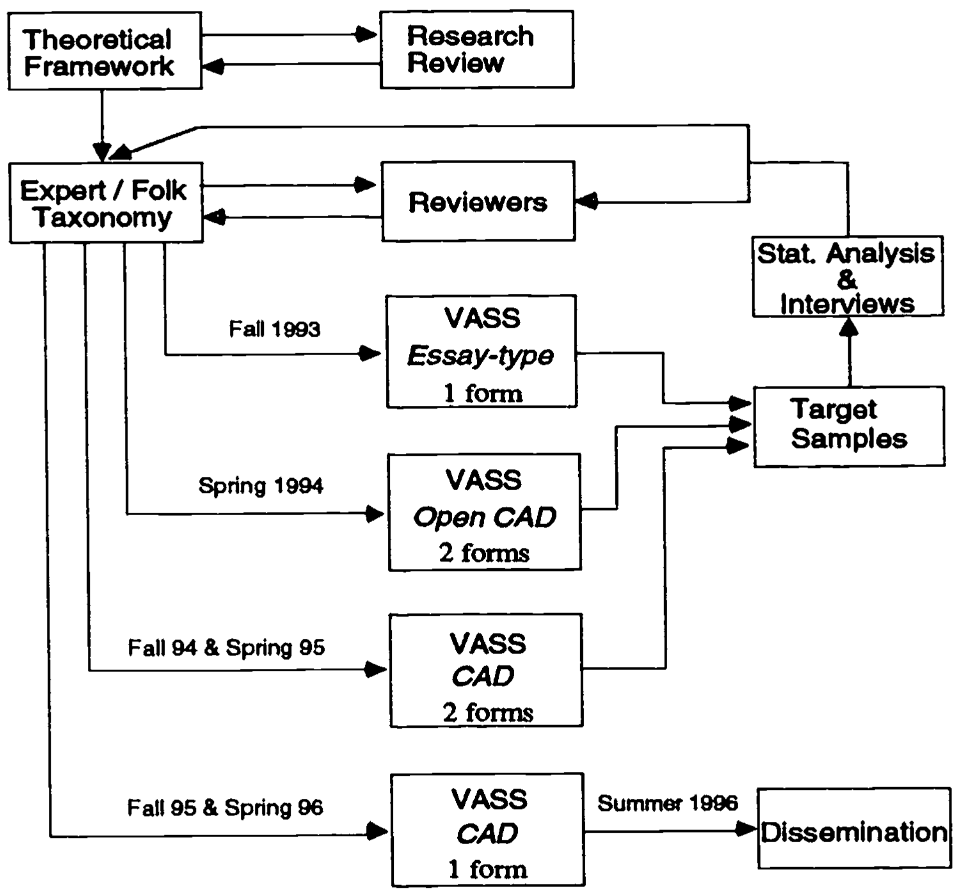

Figure 5: Evolution of VASS.

Results

The objectives presented at the beginning of the paper are assessed in this section. In order not to burden the reader with unnecessary details from different forms, we will illustrate our discussion with results from only VASS Form P11 for physics until we get to the comparison of student views in various disciplines. Furthermore, we restrict reported results to: (a) VASS forms used mostly in the current academic year 95-96 (P11, C11, and B11) for comprehensive results, and (b) one pedagogical dimension (critical thinking) and one epistemological dimension (structure), and one question within each dimension (questions 17 and 23 respectively), for itemized results. Unless otherwise specified, all data pertain to VASS pretests administered at the beginning of a course.

In reporting and discussing data, we will refer to one of the two alternatives in any given VASS item as the *expert view*, and the other as the *folk view*. In general, an alternative is referred to as the expert view if we believe that it is shared by scientists and educators at large and if it was favored by a majority of high school teachers and university professors who were administered VASS (details in the next two sections). Except for a few items*, the majority of the respondents in question was in agreement with the original classification of the alternatives that we had agreed upon with our reviewers (Figure 5).

Student and Teacher Views on Individual Items

VASS was given to a number of high school and college teachers in some participating institutions in order to: (a) establish baseline data for experts, and (b) compare students' views to their teachers'. Figure 6 shows how participating high school and college physics students and their teachers answered questions 17 and 23 respectively in Form P11.

Figure 6 shows that, when a student fails to solve a problem correctly (Item 17), 90% of 48 high school physics teachers and 89% of 26 college physics professors prefer that the student try more often to figure out how her/his method of solution differs from the one presented by the teacher (alternative (b)), rather than memorize the latter by rote. In contrast, teachers' position that students should *learn science dialectically and not by rote from authority* is shared by only 57% of 2,110 high school students (grades 9 through 12) who took VASS Form P11, and by 64% of their 351 college peers enrolled in introductory level physics courses.

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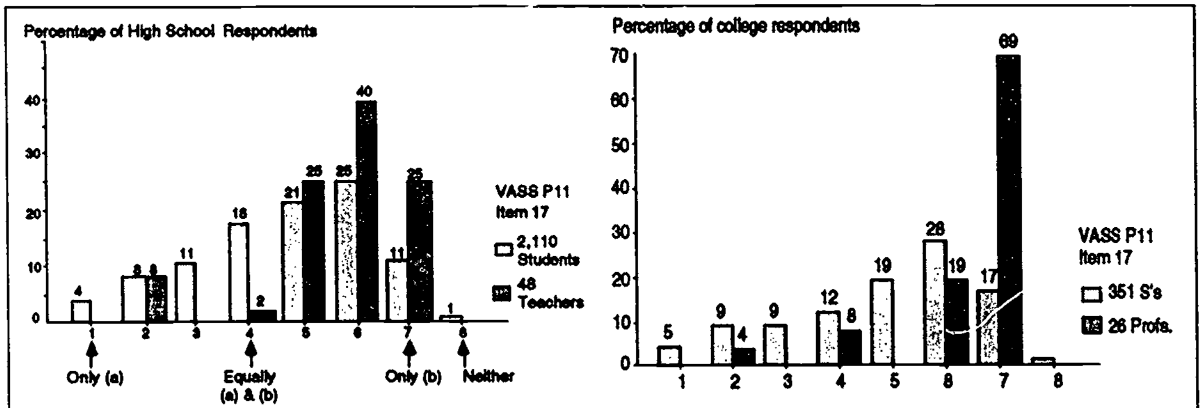
* The following two items were somewhat controversial, especially among university professors:

21. The laws of physics are:
    (a) inherent in the nature of things and independent of how humans think.
    (b) invented by physicists to organize their knowledge about the natural world.

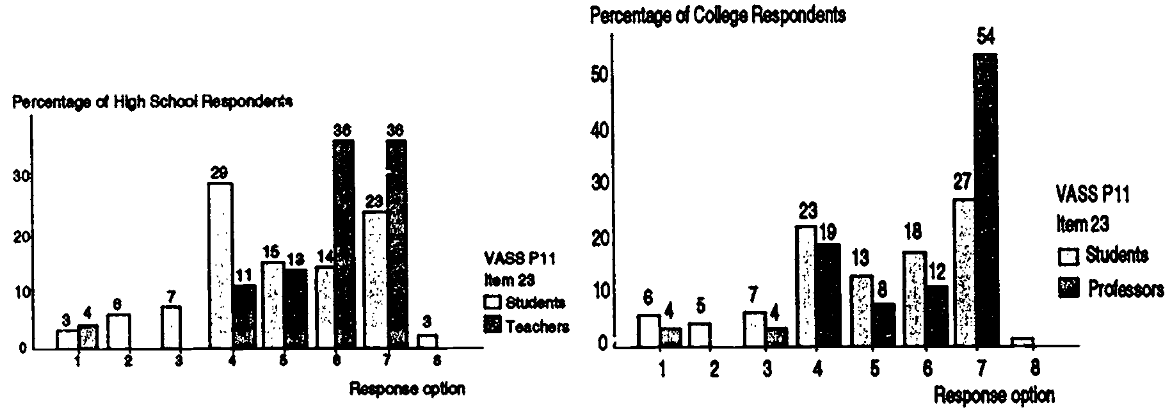
24. Newton's laws of motion:
    (a) will always be used as they are by physicists.
    (b) will eventually be replaced by other laws.

In item 21, 50% were more inclined towards alternative (a), and 31% towards (b). The rest favored equally both alternatives. We are more in favor of (b), which we consider in this paper to be the *expert* view.

In item 24, 58% were more inclined towards alternative (a), and 33% towards (b). We happen to disagree on this particular item. One of us (DH) feels strongly in favor of (a), the other (IH) feels more in favor of (b). We will rewrite this particular item in a way that would clearly keep (b) the expert view.



17. After the teacher solves a physics problem for which I got a wrong solution on my own:
    (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.



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

Figure 6: Response distributions of high school and college students and teachers on items 17 and 23 in VASS Form P11.

Similar discrepancies between teachers and students are observed in item 23 wherein the expert view that *scientific knowledge is not necessarily about directly perceived facts in the real world* is shared by 85% of high school teachers and 74% of college professors, as opposed to 52% and 58% of their students respectively.

Overall, the percentage of high school teachers who were inclined more towards expert views than folk views ranged from 71% to 96% on all but four VASS items for which the percentage was at or below 50%. The percentage of college professors showing an inclination toward expert views ranged from 73% to 100% on the various items except for the controversial ones discussed in the previous page. In contrast, the percentage of students who shared the expert views on the various VASS items ranged from 17% to 74% in high school, and from 14% to 78% in college. The number of items in which over 50% of students expressed expert views was 14 in high school and 16 in college (out of 33 items), with 13 items in common.

Figure 7 shows boxplots comparing responses of college professors and students on all 33 items of VASS Form P11. As can be seen in this figure:

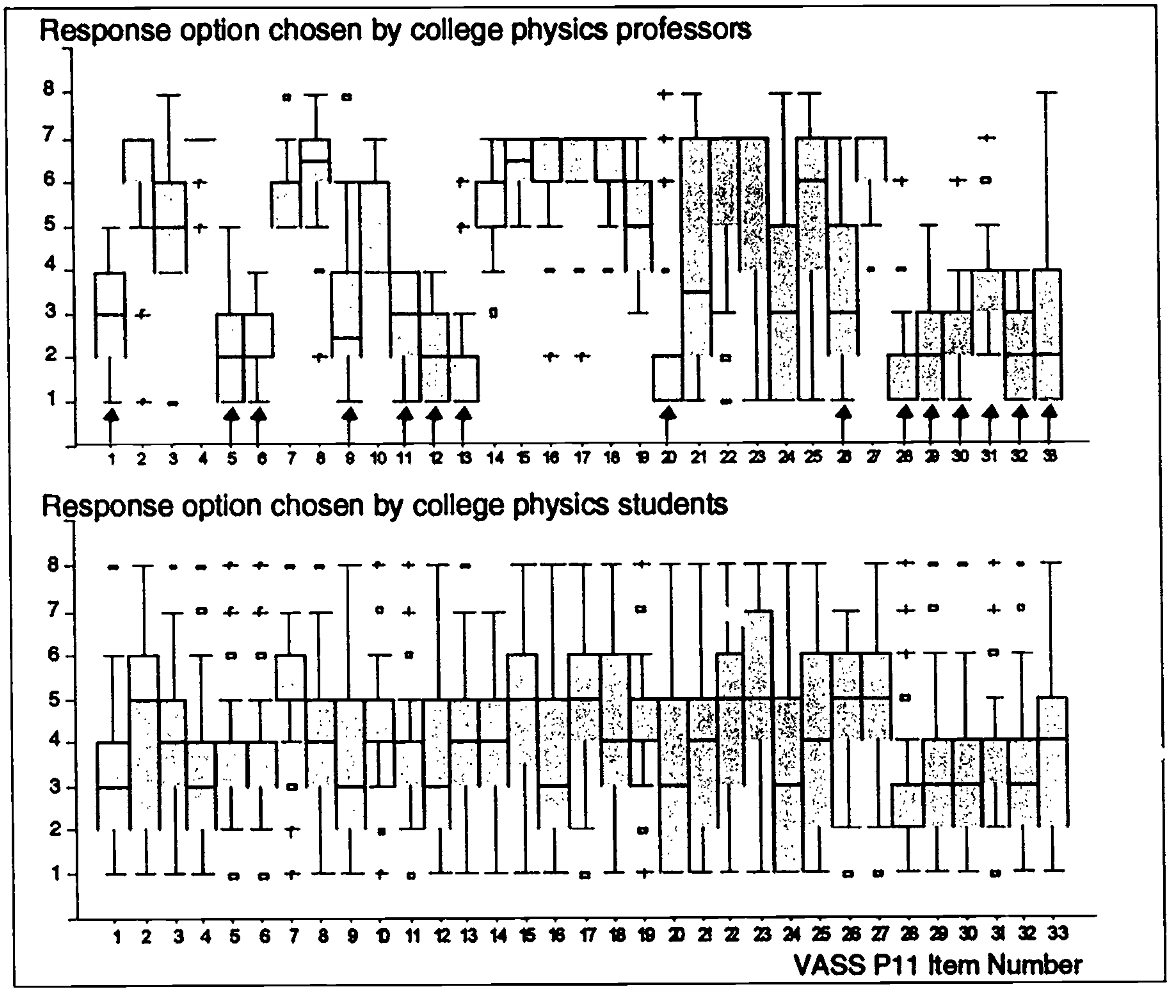


Figure 7: Boxplots showing response distributions of college physics professors (top) and students (bottom) on all items of VASS Form P11.

Each box stretches from the 25th percentile to the 75th percentile of respondents on a given item, with the median shown by a horizontal line inside the box. When the line is closer to one end of a box than another, the data are skewed in the direction of the far end. Lines drawn from the ends of a box (often called *whiskers*) stretch out to the smallest or largest value that are not outliers. *Outliers*, shown by squares, correspond to responses given by small proportions of respondents and stretching out over 1.5 box-lengths from the 25th or 75th percentiles. *Extreme* and rarest cases, shown by crosses, stretch out over 3 box-lengths from these percentiles. For a better understanding of boxplots, please compare items 17 and 23 in this figure and respective data in Figure 6.

Arrows in the top figure indicate items for which alternative (a) is the expert view. Alternative (b) is the expert view for the rest of the items.

1. Students' responses often show a larger spread on both sides of the median than professors' responses.
2. Professors' responses are narrowly clustered near the median on all but five items. These are items 21, 24, 25, 26, and 33. Except for items 21 and 24 (cf. footnote on page 10), all medians are closer to expert views than folk views.
3. Professors' responses are far more polarized than students' responses. Response option 4 (equally both alternatives) occupies the median for only one item (No. 31) in professors' responses, whereas it does the same for 14 items in students' responses. At least 25% of college students chose option 4 on these 14 items.

Responses of high school teachers were a little more spread out about the median than college professors, and their inclination toward expert views was often not as close to the extreme options (1 or 7). The same was true about high school students by comparison to college students.

A preliminary comparison of students' views to their teachers' views on individual items revealed no clear correlation. Detailed analysis of the effect of teachers' views on their students will be made after we receive all posttest data for high school students by the end of this year.

Student and Teacher Profiles

In addition to analyzing respondent positions on individual items, we were also interested in finding out to what extent these views were consistent on various items in a given dimension and in an entire VASS form. Consequently, we tried to: (a) find out whether students can be classified according to a limited number of profiles, each characterized by specific views on various items in a given dimension and in all seven dimensions, and (b) if so, analyze how these profiles affect student understanding of science and classroom achievement. Since at the time this paper was being prepared, we did not have the profile analysis completed yet, we report in this section the outcomes of the first stage of this analysis. This stage consisted of examining how consistent respondents were in expressing an inclination toward the expert view or toward the folk view across items in the chosen two dimensions and in the entire VASS Form P11.

To simplify the consistency analysis at this point, we have lumped all three response options oriented towards either alternative, i. e., response options 1, 2, & 3, for alternative (a) and options 5, 6, & 7 for alternative (b). Respondents who chose one of three options corresponding to an expert view in a given item will be referred to as showing an *expert tendency*. Those who chose an option corresponding to the folk view will be referred to as showing a *folk tendency*. Those who picked option 4 (Equally (a) & (b)) will be referred to as showing a *mixed tendency*. At this point in time, we are still trying to find out whether it is appropriate to *score* VASS, and if so, what would be the appropriate scheme. Therefore, results of our profile analysis can only be reported in an exploratory form.

As shown in Figure 8, fewer than 1% of students in each group showed an expert tendency on all nine items of the Critical Thinking dimension. 2% of high school students and 5% of college students showed the same tendency on all six items of the Structure dimensions. On the other hand, only 7% of students in each group did not show a folk tendency in any item of the Critical Thinking dimension, and 22% in each group did the same in the Structure dimension. As for the mixed tendency, it was expressed by 0.1% of high school students and none of college students in all items of the first dimension, and by 0.5% and 0.3% respectively in all items of the second dimension.

In contrast, 43% of high school teachers, and 42% of college professors showed an expert tendency on all items of the Critical Thinking dimension, and 20% and 38% respectively did the same on all items of the Structure dimension (Top inserts in Figure 8). On the other hand, 77% of high school teachers and 73% of university professors did not express a tendency towards folk views in any item of the first dimension, and 38% and 46% respectively did the same in the second dimension. As for the mixed tendency, it was not expressed consistently on all items of either dimension by any high school or college teacher.

The picture would look a little brighter if we focus on respondent consistency in at least half the items in a given dimension (5 or more for Critical Thinking, 3 or more for Structure). 31% of high school students and 40% of college students showed an expert tendency on 5 items or more in the Critical Thinking dimension, 60% and 70% respectively did the same on 3 items or more in the Structure dimension (the figures drop to 33% and 46% respectively for 4 items or more).

In contrast, and as shown in the top inserts in Figure 8, 87% of high school teachers and 96% of college professors expressed a tendency towards expert views on 5 items or more in the Critical Thinking dimension, 96% of both groups did the same on 3 items or more in the Structure dimension (81% and 85% respectively on 4 items or more).

Figure 9 shows the distributions of high school and college students who expressed a tendency towards expert views on a given number of items in the entire VASS form P11. As can be seen in this figure, not a single high school or college student showed consistent expert tendencies on all 33 items. Similarly, no student expressed consistent folk views on all items. The maximum number of items on which students expressed a tendency towards expert views was 31 in high school (1 student out of 2,110), and 27 in college (1 student out of 351). The corresponding median number was 15 items for both groups. Students who showed an expert tendency on over half the items (17 items or more) constituted 34% of the high school group and 40% of the college group.

As for teachers, and as shown in the top inserts in Figure 9, no one in high school and 12% in college expressed consistent tendency toward expert views on all 33 items. The median was 21 for high school teachers and 26 for college professors. Expert tendency on over half the items was shown by 90% of high school teachers and 96% of college professors.

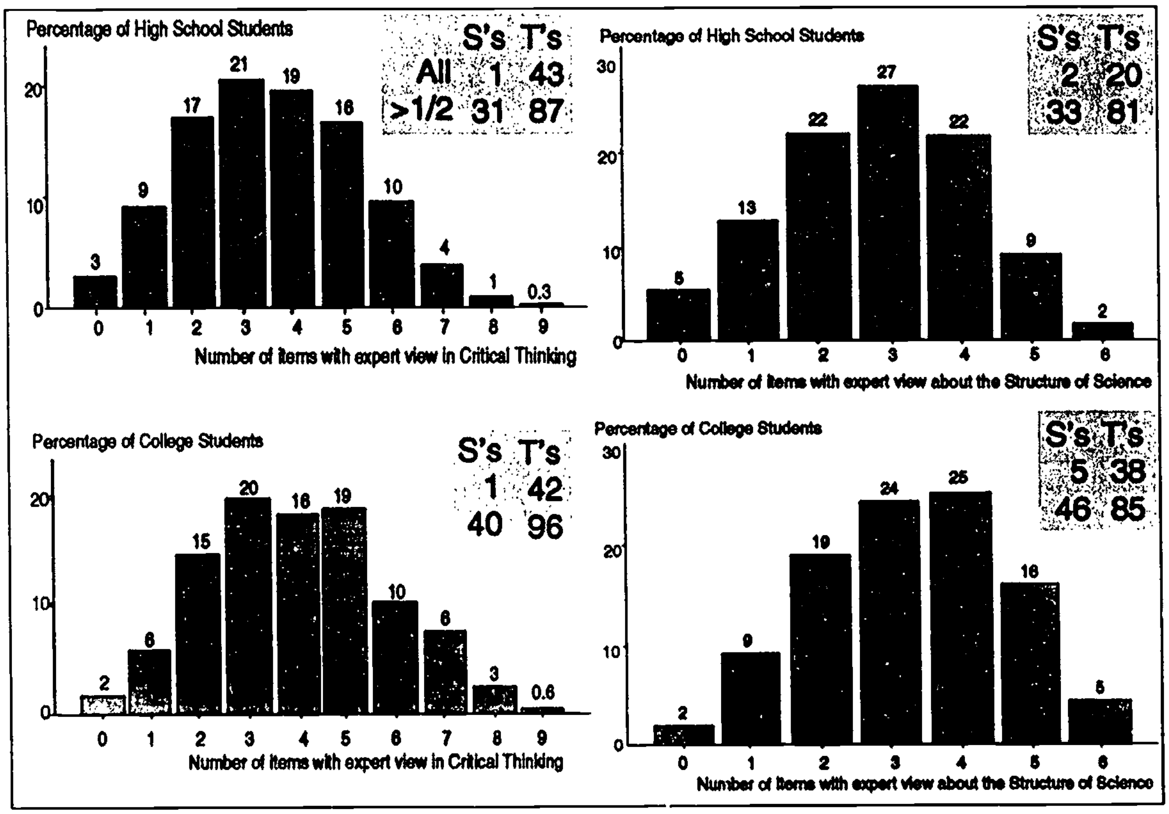


Figure 8: Distributions of high school and college students showing expert tendency on a given total number of items in Critical Thinking and Structure.

Top inserts show the percentage of students (S's) and teachers (T's) who expressed an expert tendency on all items (top row) or on more than half the items (bottom row) in a given dimension.

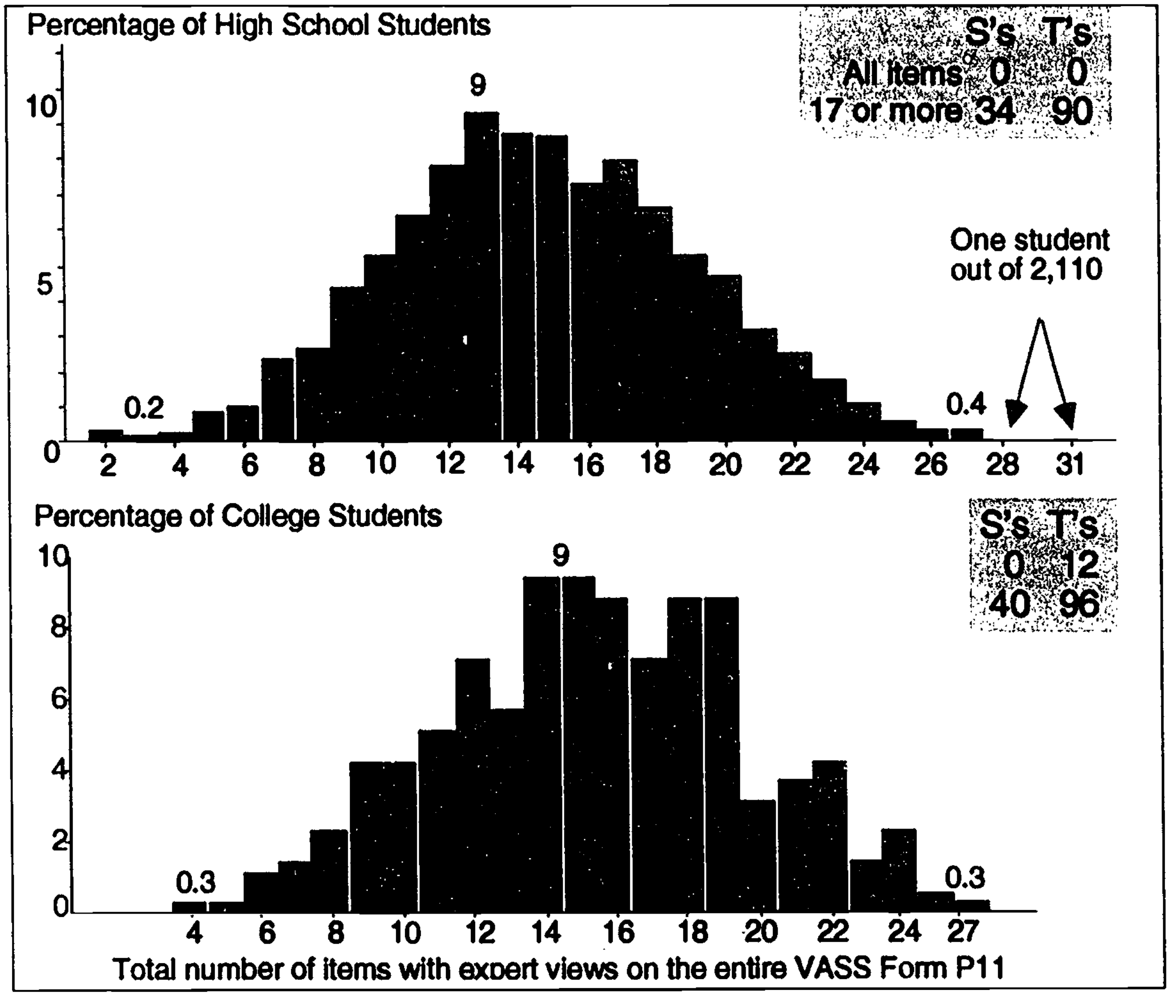


Figure 9: Distributions of high school and college students showing expert tendency on a given total number of items in the entire VASS Form P11.

Top inserts show the percentage of students (S's) and teachers (T's) who expressed an expert tendency on all items (top row) or on at least 17 items (bottom row) in the entire VASS form.

Effect of Instruction on Student Views

In order to assess the effectiveness of instruction, the same forms of VASS have been administered in some courses as pretests at the beginning of a semester (or of a year, in high schools) and as posttests at the end. Figure 10 compares pretest-posttest responses on items 17 and 23 given by physics high school students last academic year.

Figure 10 shows clearly no significant change in participating students' views on items 17 and 23. In fact, there is a minor *change in the folk direction.* High school students' views were more inclined towards folk views after instruction than before instruction. The same kind of shift was apparent in a majority of VASS items. Overall, we can draw the following conclusions that are further discussed in the next section:

1. *Traditional physics instruction has no significant effect on student views about science.*
2. On most VASS items, students tend to *shift a little more toward folk views than expert views,* after instruction.

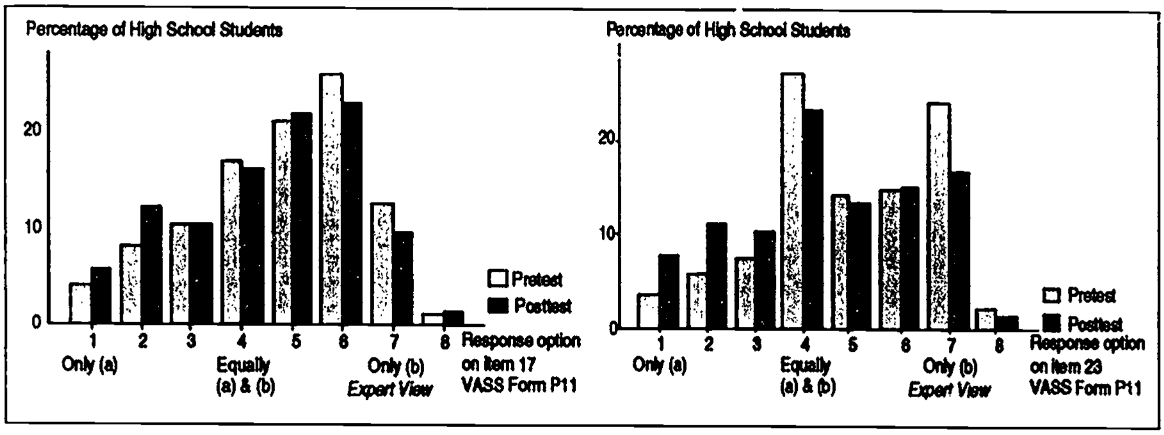


Figure 10: Pretest-posttest comparison of physics high school students' responses on items 17 and 23.

Comparison of Student Views across Grades

VASS is being administered in grades 9 through 12 in high schools, and at the freshman and sophomore levels in college. Figure 11 compares students' responses on items 17 and 23 in various high school and college physics courses. The first row compares responses of all participating high school and college students on both items (originally shown separately in Figure 6). The second row compares responses of high school students in the most common three physics courses, labeled as "Regular" (lowest level), "Honors" (upper level, offered in many high schools to honor students), and "AP". The third row compares responses of college students in the most common three introductory courses: one elementary course offered to non-science majors, a higher level algebra-based course offered to science majors outside physics and engineering, and a calculus-based course normally offered to physics and engineering majors.

As can be seen in the first row of Figure 11, overall, there are no significant differences between high school and college students' views. However, more high school students than college students showed a mixed tendency (option 4), and more college students than high school students showed an exclusive preference for the expert view (option 7). The shift is gradual across options 5 and 6. This trend of *shifting gradually from a mixed tendency to an expert tendency* as students go from high school to college was characteristic of most VASS items. However, there was virtually no shift from a folk tendency towards an expert tendency on any item.

The latter outcome depicted in Figure 11 seems not to be consistent with the outcome depicted in Figure 10. After completing high school physics courses, students drift a little closer to folk views than expert views (Figure 10). However, college students start their introductory physics courses inclined a little more towards expert views than high school students (Figure 11). There is at least one possible explanation for the apparent inconsistency. Not all high school students enter college. It is more likely that those who do are more competent and motivated than those who do not, and the more competent students are generally more inclined toward expert views as will be shown in the next section.

The same trend appears across the three high school courses with AP students getting closer to the expert views (2nd row in Figure 11), and across the three college courses with students enrolled in calculus-based courses going in the same direction (3rd row in Figure 11). However, the differences within each group are not significant and not as big as between groups. This was virtually true for all VASS items.

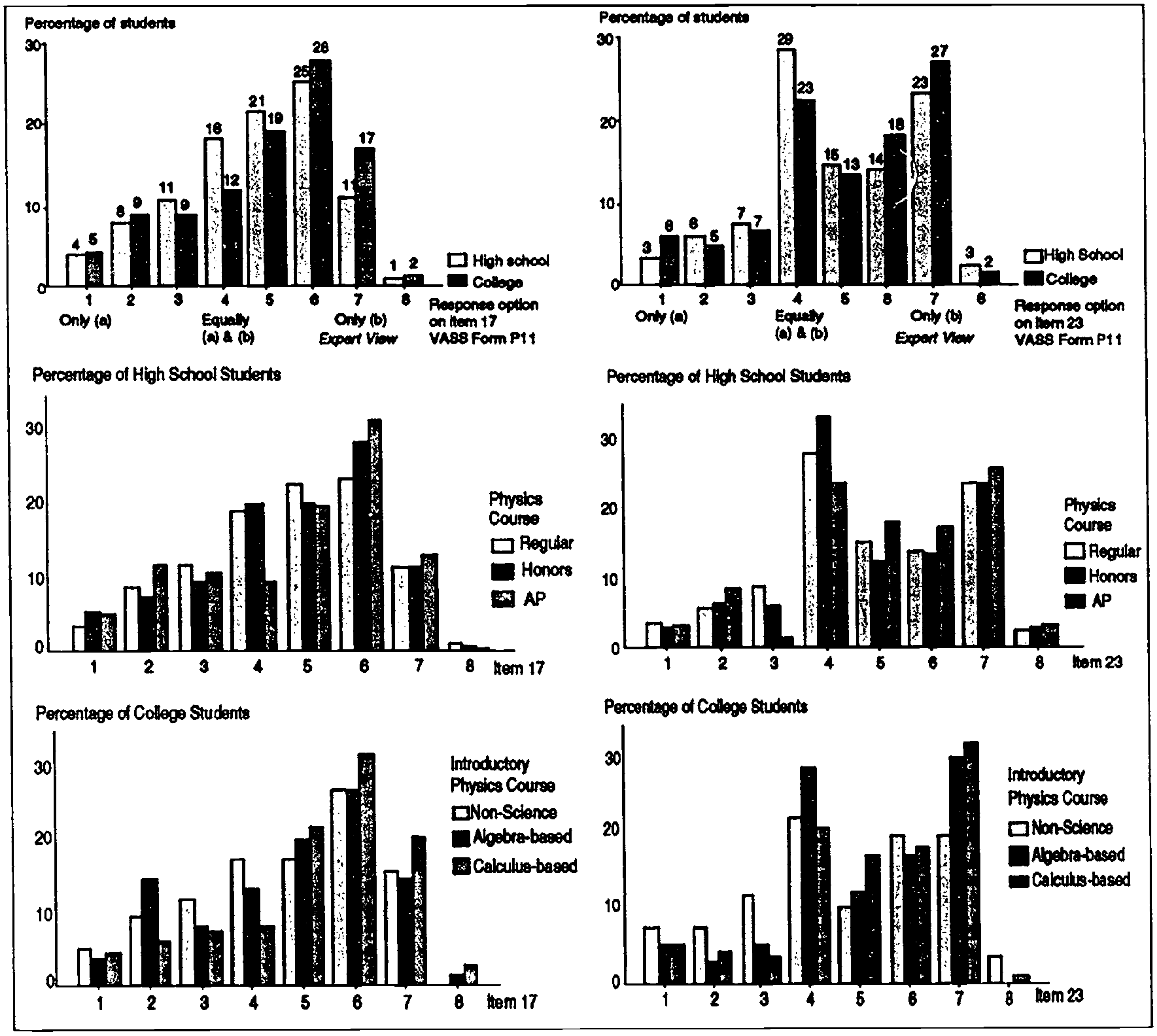


Figure 11: Comparison of high school and college students' responses on items 17 and 23 in VASS Form P11.

Figure 8 compares the performance of the same groups of students on all the items of the Critical Thinking and Structure dimensions in VASS Form P11, and Figure 9 compares the overall performance of participants on the entire form. Again these two figures, along with other results reported in the respective results section, show that *college students are more inclined towards expert views than high school students*. However, *differences within groups and between the two groups are not significant with respect to individual items or to the consistency* in expressing one tendency type or another.

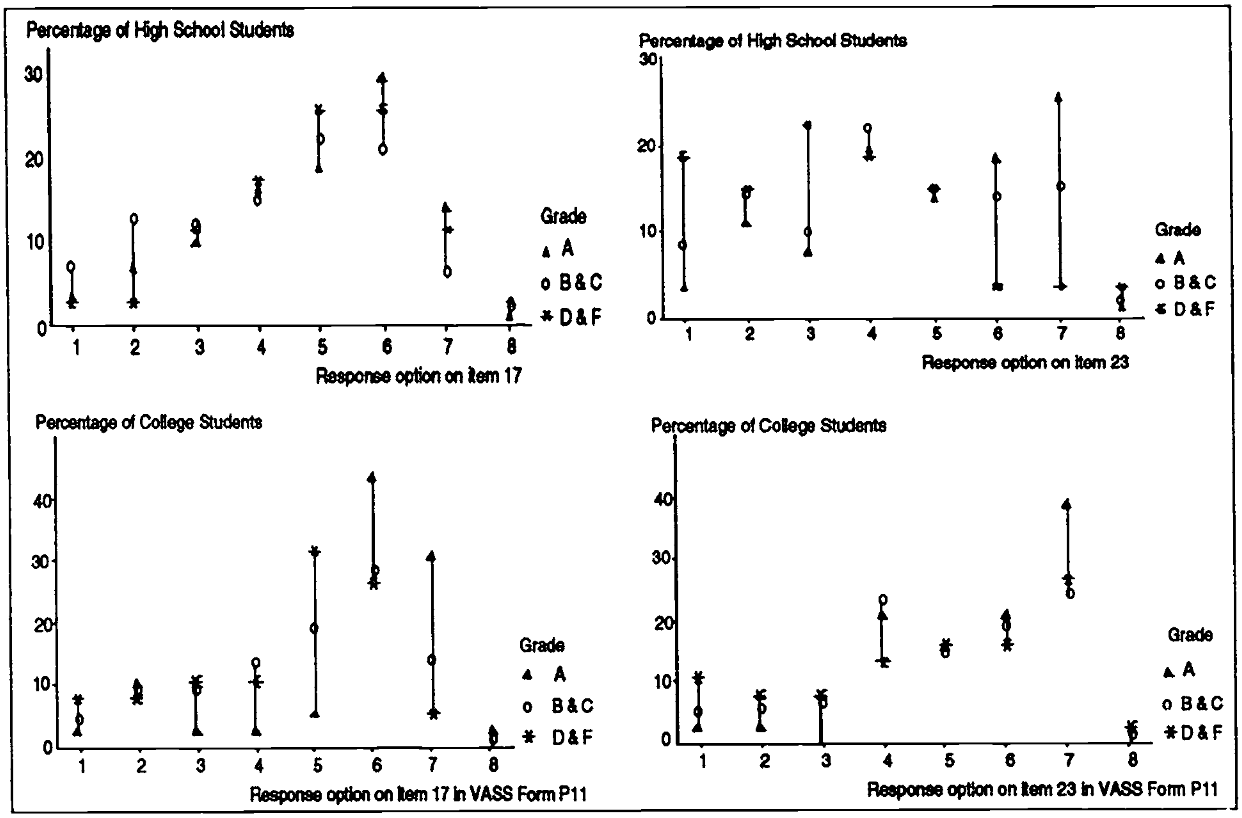


Figure 12: Distribution of high school and college students' physics grades across response options on items 17 and 23 in VASS Form P11.

Student Views and Achievement

Educational researchers have often speculated that students' views about knowing and learning science affect their understanding of what they are being taught in science courses. In order to test this speculation, we assessed the relationship between students' performance on VASS on the one hand, and their performance on standardized conceptual instruments like the Force Concept Inventory (Hestenes et al, 1992) and their final grades in their courses of enrollment, on the other hand. Different teachers have different teaching approaches and different grading schemes. Furthermore, research shows that students can often pass and even ace their science courses without necessarily understanding the material covered. Consequently, in order to have a valid and reliable assessment of students' understanding of science, it becomes necessary to supplement course grades with scores on instruments like the FCI which have been widely disseminated and shown to be valid and reliable for the assessment of conceptual understanding.

In this section, we analyze the relationship between students' grades in their courses of enrollment and VASS pretest performance, using data from the 1995 fall semester for college physics, and from the 94-95 academic year for high school physics students for the same VASS items (since we will not have high school students' grades for the current academic year until this June). Furthermore, we explore the relationship between VASS and FCI but only for high school students, since college participants were not administered the FCI.

Figure 12 shows the distribution of high school and college students' grades in their respective physics courses across the eight response options on items 17 and 23. In this figure we have lumped grades B and C as well as grades D and F. Although the contrast is

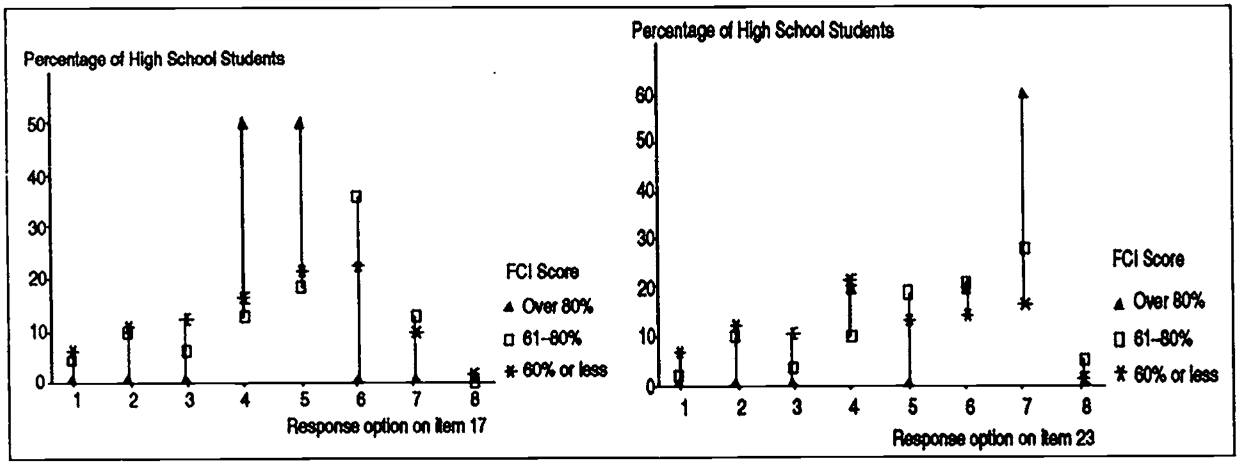


Figure 13: Distribution of high school students' on the FCI across response options on items 17 and 23 in VASS Form P11.

sharper for one item than the other, and for college students than for high school students, the figure shows a clear relationship between students' answers on VASS and their course grades. In both items, the overwhelming majority of both high school and college students with grades of A were inclined towards the expert view (alternative (b) in both cases), and there were a higher proportion of A students showing an expert tendency (options 5, 6, or 7) than any other students. Furthermore, and especially in item 23, there were a higher proportion of high risk students (grades D and F) than any others showing an inclination towards the folk view. Students in the middle category (with B and C grades) were spread out across both ends of the spectrum. Overall though, a higher proportion of this group than any other showed a mixed tendency. Similar patterns were observed throughout all VASS items so that we can conclude:

Expert views as well as folk views are shared by students from all course achievement levels. However, in most VASS items:

1. *The majority of high achievers (A students) shows a relatively consistent tendency towards the expert view.*
2. *A higher proportion of high achievers than of any other group of students is inclined towards the expert view .*
3. *A higher proportion of low achievers (D and F students) than of any other group of students is inclined towards the folk view.*
4. *A higher proportion of students in the middle category (B and C students) than in any other group shows mixed tendencies.*

Figure 13 shows the distribution of high school students' choices on items 17 and 23 in terms of their performance on the FCI. A score of 60% on the FCI is considered to be the threshold for Newtonian thinking, and a score of over 80% as near mastery level (Hestenes et al., 1992 & 1995). The inclination of students near mastery level towards the expert view is sharper on item 23 than on item 17. However, in both items, as in most of VASS items:

Virtually no student whose score is over 80% on the FCI shows a tendency towards folk views.

A higher proportion of students below the Newtonian threshold than above it show a tendency towards folk views.

Comparison of Student Views in Different Disciplines

Three separate forms of VASS with parallel items are currently available for biology (B11), chemistry (C11), and physics (P11). Like form P11, forms B11 and C11 are designed for use in high school and college. In this section, we report on the variability of students' views in the three disciplines, illustrating with results from introductory college courses.

So far, the three forms of VASS have been administered in the current academic year to 523 biology students, 345 chemistry students and 351 physics students respectively, all enrolled in introductory college level courses. Figure 14 compares responses of the three college groups on items 17 and 23 in the respective VASS forms. Figures 15 and 16 compare the performance of these groups on the two considered dimensions and the entire VASS, and Table 1 summarizes the results depicted in these two figures.

As can be seen in Figure 14, *the response trend is not the same* for the three groups on individual items, and the trend varies from one item to another. However, and as illustrated in Figures 15 and 16, as well as in Table 1, physics students were overall more consistent in expressing a tendency toward expert views than chemistry and biology students across all seven VASS dimensions. Chemistry students were more consistent than biology students in expressing such a tendency across the four epistemological dimensions. Biology students were more consistent than chemistry students in expressing a tendency towards expert views across the three pedagogical dimensions.

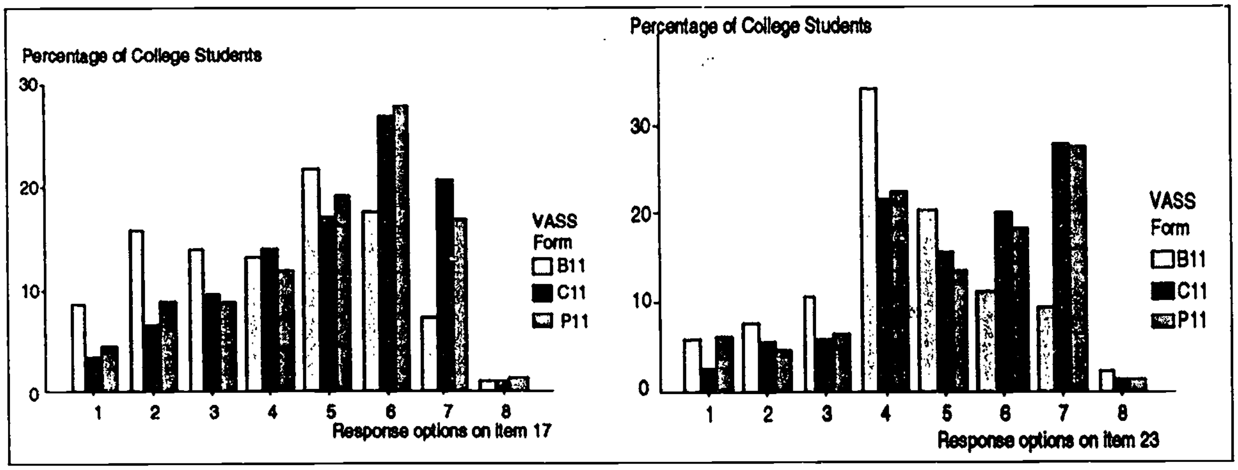


Figure 14: Distribution of college students responses on items 17 and 23 in various VASS forms.

Table 1

Percentage of college students showing consistent expert tendencies in VASS Forms B11, C11 and P11 respectively

VASS Items Group	Biology	Chemistry	Physics
All 9 Critical Thinking items	1	1	1
5 Critical Thinking items or more	35	28	40
All 6 Structure items	1	1	5
4 Structure items or more	21	38	46
17 items or more on an entire VASS	36	33	40

Virtually all traditional instruments that have been developed so far to assess student views about science do not discriminate between the various scientific disciplines. The same instrument with items talking about "science" is administered to various student groups as if there were no differences in student views regarding different disciplines. VASS results show that this is not a warranted practice, and that important information about the variability of student views across disciplines will be lost.

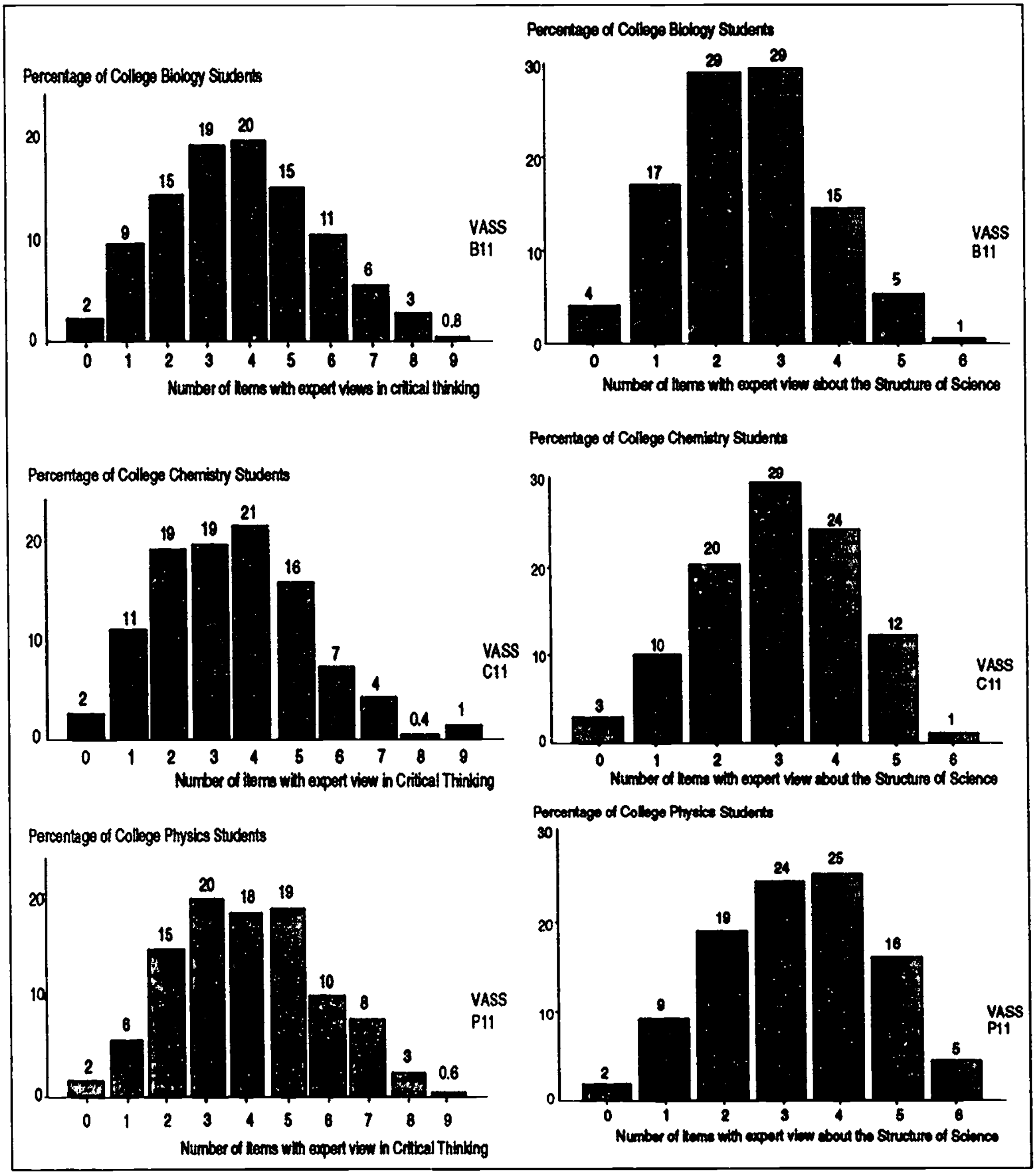


Figure 15: Distributions of college students showing expert tendency on a given total number of items in Critical Thinking and Structure in VASS Forms B11, C11 and P11.

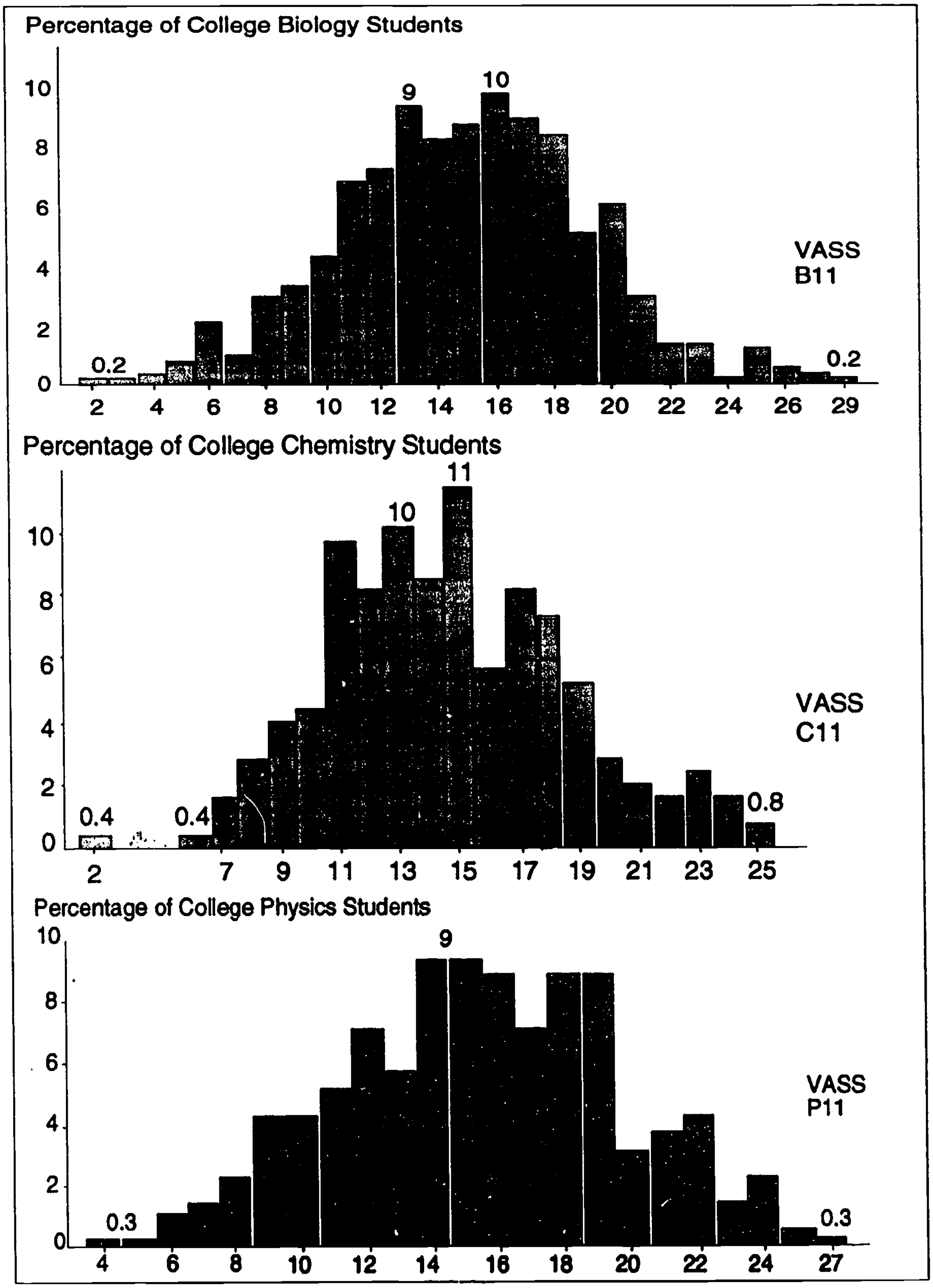


Figure 16: Distribution of college students showing expert tendency on a given total number of items in VASS Forms B11, C11 and P11.

Comparison of Student Views across Demographic Strata

In addition to CAD items assessing student epistemological and pedagogical views about science, we have documented data about the social and educational backgrounds of participants, and their expectations about the courses in which they were enrolled. The purpose was to analyze the relationship of such data to respondents views about science and classroom performance.

Social data included age, gender, ethnic background, and residence. Educational data included grade, major, number of high school and college courses completed in various scientific and mathematical fields, self-rated competence in these fields and of reading and writing skills as well as of computer skills. Course expectations were about understanding course materials and performance on homeworks, laboratory and exams.

Results pertaining to these data are beyond the scope of this paper. However, since gender is currently a hot issue in many educational and epistemological circles, it would be helpful to contribute some of what VASS shows in this respect.

Figure 17 compares female and male responses on VASS form P11 in college physics courses. Table 2 compares genders with respect to consistency in showing an expert tendency across items in the considered two dimensions and the entire VASS in college biology, chemistry and physics courses. As can be seen in these Figure and Table, gender differences are not the same across items. However, participating *college female students were more consistent than males* in expressing expert tendencies on various items within a given dimension or across an entire VASS form. This holds true in all three disciplines, although not to the same degree as can be seen in Table 2.

A similar gender comparison at the *high school* level revealed virtually *no gender difference at all*. Motivation might be a factor in this issue that shows its impact more at the college level than at the high school level.

Table 2

Gender comparison of college students' consistency in showing expert tendencies

	Biology		Chemistry		Physics	
	Female	Male	Female	Male	Female	Male
Percentage of college group	*60*	*40*	*34*	*66*	*32*	*68*
5 Critical Thinking items or more	36	34	34	25	45	36
4 Structure items or more	21	21	44	34	48	45
17 items or more on an entire VASS	38	33	34	30	41	40

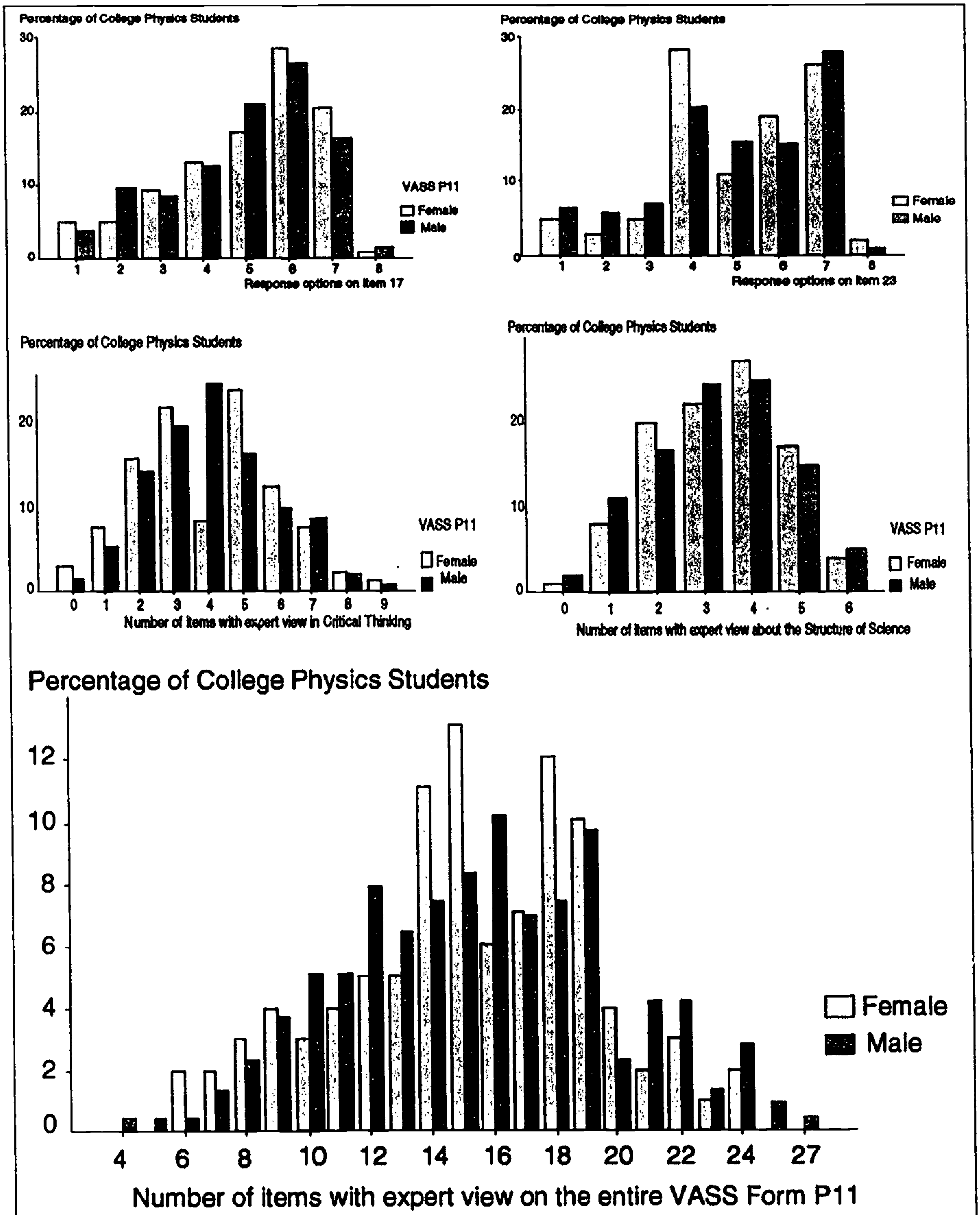


Figure 17: Gender comparison of college students' performance on VASS Form P11.

Conclusion

Following the administration of VASS to thousands of high school and college students enrolled in physics, chemistry and biology courses, and analysis of our data, we can conclude the following:

1. High school and college students hold folk views about knowing and learning science that are incompatible with views commonly held in the scientific and educational communities.

2. Students do not show a consistent tendency towards one type of views or another. Every high school and college student holds a mixture of folk and expert views about any of the epistemological and pedagogical dimensions assessed in VASS.

3. Expert views about knowing and learning science are not shared unanimously by high school teachers or university professors. There is generally a higher consent on these views among university professors than among high school teachers.

   Unlike their students who often position themselves in the middle between two contrasting views, teachers are polarized towards a specific type of views, which is most often the expert view.

4. Traditional science courses have no significant effect on students' views. Ironically, in many cases, students shift further away from expert views about knowing and learning science after completing science courses.

5. Student folk views are deep-seated and do not change significantly even after many years of high school and college schooling. A non-significant gradual shift from mixed tendencies to expert tendencies is observed in going from grade 9 through grade 14. There is virtually no shift across these grades from folk tendencies to expert tendencies or even to mixed tendencies.

6. The relationship between student views about knowing and learning science, on the one hand, and learning science, on the other hand, is not reciprocal. Learning science does not affect student views, but these views seem to affect the outcome of learning. The highest proportion of students showing a specific tendency is among high achievers for expert tendency, high risk students for folk tendency, and students in the middle category for mixed tendency.

7. Students enrolled in biology, chemistry and physics courses do not share exactly the same views about their respective disciplines, and the degree of consistency in expressing a given type of views varies from one discipline to another. Physics students are most consistent in showing an expert tendency across all seven VASS dimensions, followed by chemistry students across epistemological dimensions, and by biology students across pedagogical dimensions.

8. There are gender differences with respect to student views about knowing and learning any science at the college level but not at the high school level. Females are generally more inclined than males toward expert views, and more consistent in expressing a tendency toward such views.

Further analysis of our data is expected to reveal more information about student and teacher views about science. Among other things, we still need to undertake the following:

1. Analysis of differences between the eight options in CAD items and the relationship of individual options to understanding science.

2. Identification of a limited number of profiles, if possible, and analysis of the impact of each profile on understanding science.

3. Exploring ways for scoring VASS, and, if a valid and reliable way is found, running appropriate quantitative analysis.

4. Thorough comparison of student views and teacher views and the impact of the latter on the former.

5. Thorough analysis of VASS items in terms of demographic data.

6. Development of new VASS forms along the same and other dimensions for mathematics (in progress) and lower and upper level science courses.

Our project is an ambitious project. VASS will be disseminated at a still wider scale within and outside the USA. A large data base will be established, and continuous analysis will be conducted to learn more about student and teacher views and their impact on student understanding of science. Results will be used in the development of new science curricula at all levels.

Results that we have obtained so far with VASS and other conceptual surveys (Halloun & Hestenes, 1985–a & b; Hestenes et al., 1992) are enough to convince us that a majority of students at all levels is not benefiting enough from traditional science instruction. This deficit is apparent within the specific domain of individual disciplines as well as at the level of scientific literacy in general. Major reform is thus well justified. We have already started working in this direction within the field of physics at the high school level, and we will soon start at the college level*. With the collaboration of interested educators, work along the same lines will follow in other disciplines.

Acknowledgment

We thank all colleagues and students who made this work possible. Many colleagues participated at different levels in reviewing the various VASS versions. Dale Baker, James Birk, David Halliday, Jane Jackson, Anton Lawson and Michael Politano were especially helpful in this respect. This work would not have been possible without the voluntary and valued participation of the many schools and universities across the country. The assistance of Sharon Osborn Popp was instrumental in the statistical analysis of the data.

This work has been supported in part by the National Science Foundation.

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* For information about our reform project, please visit our worldwide web page at:

http://modeling.la.asu.edu/modeling.html

or write us at the address on the front page.

For an electronic copy of VASS, please visit the www page above, or send an e–mail request to:

Prof. Ibrahim Halloun <Halloun@asu.edu>

and specify the desired form(s) (B12, C12, P12, or M12 for mathematics. These revised forms will be available after April 20, 1996).

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