What Constitutes Effective Physics Instruction? Surveying the Views of Iowa High School Physics Teachers

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Abstract

During the spring of 2009, we invited all known Iowa high school physics teachers to respond to a series of survey questions designed to probe the current state of high school physics instruction in our state. Among other questions, the survey asked respondents to indicate the degree with which they agreed with ten statements regarding effective physics instruction, and to rate the relative importance of ten skills students might acquire in their physics courses. By dividing the respondents into two groups, traditional instructors and nontraditional instructors, we observed statistically significant differences between the views of both groups. Teachers who use inquiry-based approaches to teaching physics are more likely to have a positive view of physics first, are less likely to value a textbook's role in class, place less value on having students solve numerical problems, more strongly agree that small group work in class is essential, place more value on graphical representations, and are less likely to believe that giving directions to students is necessary prior to laboratory work.

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Introduction

Physics education research, and, more broadly, science education research, has revealed numerous difficulties students encounter while learning physics (McDermott & Redish, 1999). Delivering much of the relevant theory through a teacher-centered lecture, having students perform laboratory exercises by following explicit step-by-step instructions, and demonstrating physical principles with various apparatus while students passively observe may fail to achieve established learning goals for students. As research has revealed this gap, numerous inquiry-based, active learning approaches to the teaching and learning of physics have emerged. The National Science Education Standards, now well over a decade old, emphasize using inquiry-based teaching in the science classroom (National Research Council, 1996). Within our state, the new Iowa Core Curriculum emphasizes the presentation of science as inquiry within its standards (Iowa Department of Education, 2008). However, as anyone who has worked with educational programs is well aware, there is often a disconnect between established standards and teacher practice (Lederman 1999; McDermott 1990; Tsai 2002, 2007), which may exist for any number of reasons – for example, a lack of teacher training, interest, or time, teacher perceptions, lack of administrative pressure, or lack of resources.

Because we work at an institution that is heavily involved in providing professional development programs for secondary physics teachers in the state of Iowa, we were interested in obtaining a clearer picture of the state of high school physics instruction in our state. To that end, we constructed and delivered an online survey to all known public high school physics teachers in the state. The survey queried teachers about such items as their training and background, the courses they currently teach, what resources are available to them, and their interest and participation in various professional development opportunities.

Designing Survey Questions

The full survey report is available online (Morgan & Kittleson, 2009), and additional findings are the subject of other manuscripts. We wish to focus this discussion on the results of two questions we asked teachers, intending to elicit their views on effective teaching and learning in a physics course. Through these questions, we hoped to obtain a picture of teacher views on the proper place of physics in the high school science curriculum, the effectiveness of certain tools, techniques, and practices, how they viewed teacher-student and student-student interactions, and what skills, abilities, and knowledge they felt were important for future work.

Previous research

Recently, various calls have been made for a reexamination of the sequence of high school science courses in the majority of American high schools, where the typical order of core courses is biology, chemistry, and finally physics. Notably, Nobel laureate Leon Lederman has called for physics to be taught first in the high school science sequence (Bardeen & Lederman, 1998; Lederman, 2001, 2005). Sheppard and Robbins (2002, 2003, 2005) have pointed out that the current pattern of teaching biology first has not always been the case, and in earlier times, physics was taught early in the secondary science sequence, and to a wider audience. The American Association of Physics Teachers (AAPT, 2002) issued a statement on physics first, and offers resources to schools interested in switching sequence.

O'Brien and Thompson (2009) compared the performance of ninth-grade physics courses with twelfth-grade physics courses in Maine, finding that in certain cases ninth-grade students outperformed twelfth-grade students on conceptual learning gains. Liang, Fulmer, Majerich, Clevenstine, and Howanski (2012) found similar results when comparing ninth-grade students in a modeling environment vs. twelfth-grade students in a more traditional setting in two Mid-Atlantic high schools.

A few school districts in Iowa have experimented with ninth grade physics, and anecdotal reports we've heard on its efficacy have been mixed. (We are unaware of any formal studies conducted in our state comparing ninth and twelfth-grade physics performance.) As a result, we were interested in how our state's physics teachers viewed the idea of placing physics first in the high school science sequence.

Arguments for and against physics first are often related to mathematics. Opponents argue that putting physics early in the high school science sequence requires the mathematical structure inherent in a physics course to be "watered down" or removed. Proponents argue that taking physics concurrent with algebra might strengthen students' mathematical understanding. These views have been gleaned from blogs and discussions at conferences; to our knowledge, neither camp has systematically studied the issue.

Several studies have, however, examined the link between mathematical proficiency and performance in physics courses. More than thirty years ago, Hudson and McIntire (1977) found that mathematical ability alone does not predict physics success, but success in an introductory college-level physics course was not achieved without mathematical skill. Meltzer (2002) has shown that pre-instruction scores on a physics concept test do not correlate with learning gains in the course, but there is correlation between learning gains and pre-instruction mathematical skill.

Since many inquiry-based approaches focus on building conceptual understanding, students are frequently asked to explain their reasoning, often in writing, in addition to (or in place of) more traditional mathematical problem solving. Hein (1999) showed that having students write about physics helps them confront misconceptions in their understanding. We included questions to ascertain teachers' views of their students' mathematical and writing abilities when entering their physics courses.

Regardless of where physics occurs within the high school curriculum or the prior preparation of one's students, teachers must make decisions about what activities will fill available class time. Will she or he lecture? Perform demonstrations? Engage students in laboratory experiments? Will there be homework? What types of questions will appear on assignments and assessments?

Long a hallmark of physics courses and a favorite of many physics instructors, some have recently questioned the effectiveness of demonstrations for student learning. Roth, McRobbie, Lucas, and Boutonné (1998) showed that students who lack a coherent framework for the physics being studied may often be confused by what is being presented, and have trouble distinguishing the key behavior from other occurrences during the course of the demonstration. Students who passively observe demonstrations often learn no more than students who don't see the demonstrations. Demonstrations can be made more effective, however, by requiring students to make predictions prior to the demonstration, and/or explanations after observing the demonstration (Crouch, Fagen, Callan, & Mazur, 2004; Sokoloff & Thornton, 1997). In our survey, we included a question probing how teachers viewed the role of demonstrations in their classrooms. (We note, however, that we made no attempt to determine whether teachers required their students to passively observe the demonstrations or actively predict or explain their observations.)

Textbooks are widely used, and many teachers rely heavily on textbooks as sources of information (Moore & Murphy, 1987). Many critics have called into question the accuracy and efficacy of various science textbooks (for example, Bohren, 2009; Hubisz, 2001, 2003). While this has led some to call for the reduced use of textbooks (Daniels & Zemelman, 2004), others have shown how textbook errors can be used to help teach physics (Campanario, 2006). Whether or not textbooks are used, Sadler and Tai (2001) showed that students who have taken high school physics in a setting that spends more time on fewer topics outperform those who cover large quantities of content in a textbook-centered environment. We were interested in seeing how our surveyed teachers viewed the role of the textbook within their classrooms.

Physics textbooks often include large numbers of end-of-chapter questions and problems that can be answered in class or assigned as homework. The emergence of standardized conceptual tests such as the Force Concept Inventory (Hestenes, Wells, & Swackhammer 1992) and the Force and Motion Conceptual Evaluation (Thornton & Sokoloff 1997) have shed light on students' frequent failure to develop conceptual understanding of physics in classrooms with minimal or no use of interactive engagement methods (Hake, 1997), even if students engage in lots of problem solving. As a result, many instructors adopting research-based pedagogies have placed more emphasis on building conceptual understanding, and less emphasis on numerical problem solving (often referred to as "plug and chug" when the problems require plugging in given values for variables in an equation). We were interested in ascertaining teacher views on both numerical problem solving and conceptual questions.

In addition to choosing instructional activities, teachers interact with students in various ways throughout any given class period. Additionally, many teachers work to actively facilitate student-to-student interactions during the learning process.

Constructivism, the idea that students must build their own understanding, lies at the heart of most inquiry-based approaches to teaching science. If one teaches from a constructivist framework, students are allowed to experiment without being told answers; rather, they are frequently engaged in an ongoing dialogue about what they are learning (Shulman, 2000), a rather complex interchange when compared with straightforward lecture. Socratic dialogue has been successfully deployed in physics laboratories at the college level (Hake, 1992). We expect that constructivists would argue that it's important to not answer all student questions, but instead guide them toward activities and discussions that will help them answer their own questions. We were interested in the degree to which surveyed teachers thought it was important to answer student questions.

Research has also called into question the effectiveness of so called "cookbook" laboratory exercises, where students are given a step-by-step "recipe" for completing the activity (Clough, 2002; Lochhead & Collura, 1981; Luckie, Maleszewski, Loznak, & Krha, 2004; Roth, 1991; Royuk & Brooks, 2003). We were interested in finding out whether or not the high school teachers we surveyed utilized "cookbook" labs or more constructivist approaches.

Many of the research-based approaches to teaching physics rely on a significant amount of small group work, both in conducting experiments and discussing questions and ideas. Springer, Stanne, and Donovan (1999), reviewing research performed across the disciplines of science, technology, engineering, and mathematics, revealed that small-group work is effective in improving both student learning in courses and student attitudes across the various disciplines. Heller, Keith, and Anderson (1992) showed that college-level introductory physics students solve problems better when doing so in groups, and the experience raises the proficiency of all group members. With new emphases on inquiry-based science instruction in our state, we wanted to know how much instructors valued group work in their physics courses.

Question 1: Important Elements

Based on the ideas discussed above, we presented participating teachers with ten statements regarding the teaching of physics, and asked them to indicate their level of agreement with each:

> Different physics instructors have varied opinions on the important elements of physics teaching. Please indicate your degree of agreement with the following statements about effective instruction. (1=Strongly Disagree, 5=Strongly Agree)
>
> 1. Giving students directions (written or verbal) when they begin a lab is very important.
> 2. Students learn a lot of physics by solving numerical problems.
> 3. Students learn a lot of physics by answering conceptual questions.
> 4. Demonstrations are helpful in getting my students to understand physical principles.
> 5. It would be best if students took physics prior to taking biology or chemistry.
> 6. In general, my students have adequate mathematical skills when entering my physics course(s).
> 7. In general, my students have adequate writing skills when entering my physics course(s).
> 8. A textbook is an important tool for a physics course.
> 9. Group work is an important element of learning in my physics course.
> 10. To teach physics effectively, it's important to answer all (or most) student questions.

(As has been pointed out subsequent to the survey, the first statement we included rather general and might have been better as "step-by-step directions," as we were hoping to measure the prevalence of cookbook labs. Most instructors, unless they practice true open inquiry instruction, give some form of directions when commencing a new classroom activity, even though they may not detail the entire procedure required to complete an experiment.)

Question 2: Preparation for Future Work

Often in the course of offering professional development programs for high school physics teachers in our state, we are asked, "what do we need to teach our students to get them ready for your (college-level) class?" As physics is often seen as a course for college bound students, frequently populated by students who will take physics again at the college level, we were interested in finding out how the surveyed teachers viewed their role in preparing the students for future physics courses. To that end, the survey included the second question of interest:

> Think about the students in your physics course(s) who are likely to take a physics course in college. In your view, what skills or knowledge are most important for their future success? Please rank the following skills or knowledge elements from 1 (most important) to 10 (least important.)
>
> _ The ability to work in a group to solve a problem or conduct an investigation.
>
> _ The ability to answer conceptual questions.
>
> _ The ability to graph and interpret data.
>
> _ The ability to make measurements and collect data.

_ The ability to algebraically manipulate physics equations and solve numerical problems.

_ The ability to communicate scientific ideas verbally.

_ The ability to communicate scientific ideas in writing.

_ Knowledge of physical laws and/or formulas.

_ The ability to read a textbook for understanding.

_ The ability to draw sketches or diagrams.

We note that many of these statements are similar to those found in the previous agree-disagree list of statements. However, we included them in this form since one might conceivably agree to all the previous statements when answering the previous question, and we were interested in determining teachers' highest and lowest priorities in the classroom.

Methodology

We wrote the initial survey questions in the spring of 2009. The survey contained six sections of questions, focused on (*i*) demographic information about the teachers, (*ii*) physics content addressed during their physics course(s), (*iii*) pedagogy, (*iv*) resources (both equipment and money) available to teachers, (*v*) connections, inquiring about the preparation of their incoming and outgoing students, and (*vi*) professional development.

We uploaded our questions to an online survey-hosting website, and invited three area master high school physics teachers who often collaborate with the physics department on professional development programs to preview the survey. Their feedback informed the editing of several survey questions. Three hundred seventy-one Iowa high school physics teachers (all known high school physics teachers in the state at the time of the survey) were electronically invited to complete the survey; those who had not responded within one week were sent reminder emails. After a total of three weeks, access to the survey was shut down, and results were tabulated. One hundred fifty-one of the 371 invitees (40.7%) completed the entire survey; only responses of those who completed the entire survey were used in our analysis.

An electronic-only survey might generate a sampling bias, with younger respondents perhaps more likely to engage in a series of online questions. While we made no attempt to actively combat this possibility, we note that 66% of respondents who completed the survey reported teaching careers of more than 10 years, and 34% reported teaching careers of more than 20 years. Thus, we feel that our sample was unlikely to be skewed by the views of younger respondents.

In addition to examining the responses for all respondents collectively, we used the response to another survey question to divide the teachers into two groups. A question in the pedagogy section of the survey asked respondents whether or not they utilized any nontraditional approaches to physics teaching in their classrooms. Respondents could indicate that they used Active Physics (Eisenkraft, 2005), Comprehensive Conceptual Curriculum for Physics (C^3P) (Olenik, 2009), Constructing Physics Understanding (CPU) (Goldberg, 1997), the Modeling

Instruction Program (Hestenes, 1987), Physics by Inquiry (McDermott, 1995; McDermott, Shaffer, & Constantinou, 2000), Physics Resources and Instructional Strategies for Motivating Students (PRISMS) (Cooney, Escalada, & Unruh, 2007), RealTime Physics (Sokoloff, Thornton, & Laws, 2004; Sokoloff, Laws, & Thornton, 2007), Workshop Physics (Laws, 1997, 2004), some other program, or that they did not use any nontraditional approaches.

Slightly more than half of respondents (n = 86, 57%) reported using one or more nontraditional approaches. Responses of these teachers, which we called the "nontraditional" group, were analyzed and compared with responses from teachers who indicated that they used no nontraditional approaches – the "traditional" group (n = 65, 43%). (No survey questions asked respondents about the degree to which they employed the nontraditional methods, so the nontraditional moniker likely covers those who employ a particular curriculum for their entire course as well as those who may have tried an activity or two to supplement their more traditional approach. However, 45 of the 86 users of nontraditional methods report using more than one approach, and 13 of the 86 report using self-developed materials consistent with an inquiry approach, so it is unlikely that our nontraditional group contains large numbers of teachers who employ mostly traditional instructional techniques.)

We hypothesized that nontraditional teachers would be more likely than their traditional colleagues to value (*i*) asking conceptual questions, (*ii*) the idea of physics preceding biology and chemistry, and (*iii*) group work. We thought the nontraditional teachers would be less likely than their traditional colleagues to value (*i*) giving explicit directions when beginning an experiment, (*ii*) numerical problem solving, (*iii*) performing demonstrations, (*iv*) a textbook as a central course tool, and (*v*) answering student questions (preferring to let students develop their own answers.) We expected to see no difference in the two groups' views of the mathematical and writing skills of their incoming students, though one could hypothesize that nontraditional teachers might be more optimistic about the mathematical skills of their students, if they spent less time in class on numerical problem solving where the lack of such a skill is often exposed.

Results

Statements about effective teaching

Table 1 indicates the degree to which the surveyed teachers agreed with each of the ten statements on the first question. Category response percentages for all instructors are shown first after each statement, followed by response percentages for traditional and nontraditional instructors.

Table 1

Degree of agreement with ten statements regarding effective physics instruction.

Statement		Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly Disagree (1)
1. Giving students directions (written or verbal) when they begin a lab is very important.	**All**	**16%**	**51%**	**21%**	**11%**	**1%**
	T	26%	49%	18%	6%	-
	NT	8%	52%	22%	15%	2%

2. Students learn a lot of physics by solving numerical problems.	**All**	**8%**	**50%**	**26%**	**14%**	**1%**
	T	11%	65%	22%	3%	-
	NT	6%	40%	30%	22%	2%
3. Students learn a lot of physics by answering conceptual questions.	**All**	**25%**	**66%**	**9%**	**1%**	**-**
	T	23%	71%	6%	-	-
	NT	26%	63%	10%	1%	-
4. Demonstrations are helpful in getting my students to understand physical principles.	**All**	**28%**	**55%**	**13%**	**3%**	**1%**
	T	34%	52%	12%	2%	
	NT	23%	57%	14%	5%	1%
5. It would be best if students took physics prior to taking biology or chemistry.	**All**	**6%**	**5%**	**46%**	**33%**	**11%**
	T	2%	5%	29%	48%	17%
	NT	9%	5%	58%	22%	6%
6. In general, my students have adequate mathematical skills when entering my physics course(s).	**All**	**13%**	**46%**	**17%**	**23%**	**1%**
	T	17%	40%	17%	25%	2%
	NT	10%	50%	17%	21%	1%
7. In general, my students have adequate writing skills when entering my physics course(s).	**All**	**3%**	**54%**	**26%**	**15%**	**1%**
	T	3%	57%	28%	12%	-
	NT	3%	52%	26%	17%	1%
8. A textbook is an important tool for a physics course.	**All**	**7%**	**38%**	**30%**	**19%**	**5%**
	T	17%	38%	26%	17%	2%
	NT	-	38%	34%	20%	8%
9. Group work is an important element of learning in my physics course(s).	**All**	**45%**	**50%**	**5%**	**1%**	**-**
	T	29%	65%	6%	-	-
	NT	57%	38%	3%	1%	-
10. To teach physics effectively, it's important to answer all (or most) student questions.	**All**	**15%**	**31%**	**30%**	**19%**	**5%**
	T	17%	35%	34%	14%	
	NT	13%	28%	27%	23%	9%

Note. T = traditional instructors; NT = nontraditional instructors. Percentages of all respondents in each category are shown in boldface; traditional and nontraditional response percentages are shown in the subsequent rows. All percentages were rounded to nearest integer values, so rows may not sum to exactly 100%.

An examination of the responses of all teachers to statements about effective physics teaching, shown in Table 1, reveals the following:

- About two-thirds of all teachers agree that giving students directions at the commencement of a laboratory experiment is important.

- More than one-half of all teachers agree that students learn a lot of physics by solving numerical problems, but one-quarter of teachers are neutral on that statement.
- Most teachers (90%) agree or strongly agree that students learn a lot of physics by answering conceptual questions (many more than agree to the idea of solving numerical problems.)
- More than 4 in 5 teachers agree that demonstrations are effective for student learning.
- Overall, most teachers are neutral on or opposed to the idea of physics first.
- In general, the surveyed teachers were positive regarding the mathematical and writing preparation of their incoming students; those that disagreed were more negative about their students' mathematical skills than writing skills.
- While the distribution of responses tends to skew slightly toward the "agree" side on the importance of using a textbook, nearly 1 in 4 teachers disagree with this statement.
- Most instructors (95%) value group work in their physics class.
- Almost half of teachers agree that it's important to answer the majority of student questions in class, but one-fourth disagree and a nearly a third are neutral on this statement.

We next examined whether there were differences in the response patterns when separated into two groups, those being the aforementioned traditional and nontraditional instructors. We performed a Mann-Whitney U test on each of the ten question statements, comparing the agreement patterns of the two groups. Table 2 includes the ten statements in descending order of statistically significant differences, and reports *U*, *z*, and two-tailed *p*-values for each statement.

Table 2

Statistical comparison of the responses of traditional and nontraditional instructors to statements regarding effective physics instruction.

Statement	*U*	*z*	*p*
5. It would be best if students took physics prior to taking biology or chemistry.	3872	4.05	0.0001
2. Students learn a lot of physics by solving numerical problems.	3772	3.67	0.0002
9. Group work is an important element of learning in my physics course(s).	3551	2.84	0.0045
1. Giving students directions (written or verbal) when they begin a lab is very important.	3539	2.79	0.0053
8. A textbook is an important tool for a physics course.	3512	2.69	0.0071
10. To teach physics effectively, it's important to answer all	3366	2.14	0.0324

(or most) student questions.			
4. Demonstrations are helpful in getting my students to understand physical principles.	3174	1.42	0.1556
7. In general, my students have adequate writing skills when entering my physics course(s).	2962	0.62	0.5353
3. Students learn a lot of physics by answering conceptual questions.	2849	0.20	0.8415
6. In general, my students have adequate mathematical skills when entering my physics course(s).	2792	0.01	0.9920

The first two statements (5 and 2) show highly significant differences in the Likert responses of the two groups. The next three statements (9, 1, and 8) show moderately significant differences between groups. The sixth statement (10) shows a slight difference between groups, while the final four statements show no statistically significant differences between groups.

We also performed a chi-squared test of independence on the distributions of responses of the two groups to each statement. While we observed slight variations in the order of significance, the same first five statements on Table 2 had *p*-values on the chi-squared test of < 0.05, indicating statistically significant differences between the groups. This is consistent with the observations of others who have observed similar patterns when comparing the *t*-test and the Mann Whitney Wilcoxon for five-point Likert items (de Winter & Dodou, 2010).

Important skills or abilities

Table 3 shows the results of our second question under discussion, which asked teachers to rank the importance of various elements of a physics course for future study within the discipline. Although there is a wide variance in the rankings from instructor to instructor, we determined overall rankings for the entire group by assigning each first place vote ten points, each second place vote nine points, etc., summing the points attributed to each statement by all teachers, then ranking the skills by total points earned.

The results are shown for all respondents, and also separated to show the rankings of traditional and nontraditional teachers. The large number in each group column indicates the overall integer ranking, and the table presents the ten statements in order of ranking for all respondents. These rankings, however, may be deceptive and suggest larger differences that we observed between items. Therefore, we also include the mean (*M*) and standard deviation (*SD*) of all rankings of a particular statement for a particular group, allowing the reader insight into item separation. (For example, the items that rank 8th and 9th for traditional teachers are separated by an average of the rankings of only 0.03.) We again tested for statistically significant differences with the Mann Whitney U test, comparing all rankings for traditional and nontraditional teachers for each statement. In Table 3, we also include *U*, *z*, and *p* values (two-tailed) for each statement.

Table 3

Rankings of the relative importance of various skills and abilities developed through a physics course.

Skill or Ability		Instructor Ranking All	T	NT	*U*	*z*	*p*
The ability to work in a group to solve a problem or conduct an investigation.	R	1	2	1	3258	1.74	0.0818
	M	3.69	4.05	3.42			
	SD	2.59	2.56	2.60			
The ability to answer conceptual questions.	R	2	3	4	2979	0.69	0.4893
	M	4.57	4.37	4.72			
	SD	2.66	2.47	2.80			
The ability to graph and interpret data.	**R**	**3**	**6**	**2**	**3849**	**3.96**	**0.0001**
	M	**4.66**	**5.57**	**3.97**			
	SD	**2.30**	**2.38**	**1.98**			
The ability to make measurements and collect data.	R	4	4	3	3189	1.51	0.1299
	M	4.70	5.02	4.45			
	SD	2.32	2.36	2.28			
The ability to algebraically manipulate physics equations and solve numerical problems.	**R**	**5**	**1**	**6**	**3736**	**3.54**	**0.0004**
	M	**4.91**	**3.95**	**5.64**			
	SD	**2.92**	**2.74**	**2.86**			
The ability to communicate scientific ideas verbally.	R	6	8	5	3322	1.98	0.0476
	M	5.75	6.22	5.41			
	SD	2.67	2.83	2.49			
The ability to communicate scientific ideas in writing.	R	7	9	7	3001	0.77	0.4388
	M	6.11	6.25	6.00			
	SD	2.28	2.46	2.14			
Knowledge of physical laws and/or formulas.	R	8	5	8	3375	2.18	0.0293
	M	6.15	5.54	6.62			
	SD	3.03	3.08	2.92			
The ability to read a textbook for understanding.	R	9	7	10	3416	2.33	0.0197
	M	6.83	6.08	7.41			
	SD	3.02	3.22	2.74			
The ability to draw sketches or diagrams.	R	10	10	9	3388	2.23	0.0260
	M	7.46	7.97	7.07			
	SD	2.40	2.18	2.51			

Note. T = Traditional instructors; NT = nontraditional instructors; R = Rank. Statements with highly significant differences between traditional and nontraditional instructors are in boldface.

Discussion

In the following sections, we discuss items where we observed statistically significant differences between the responses of the traditional and nontraditional teacher groups. First, we discuss each of the survey questions individually, then comment on overall themes that develop when looking at the responses to both questions together.

Effective teaching statements: Highly significant differences

With regards to physics first, that is, having a high school physics course precede biology and chemistry courses, the largest subset of nontraditional instructors indicate neutrality on the idea; only 14% agree with this idea. However, more than half of traditional instructors disagree or strongly disagree with the idea of physics first, compared with just over a quarter of nontraditional instructors. Thus, we can generalize the results to say that although neither group strongly favors the idea, nontraditional instructors are more open to physics first. This may be because they have experimented with instructional methods that they feel would work for teaching physics to populations of students who are early in their high school careers.

There is also a significant difference in views about the role of numerical problem solving. Over three-quarters of traditional instructors either agree or strongly agree that numerical problem solving is an important element of a physics course, compared with less than half of the nontraditional instructors. Again, this is consistent with the observation that many traditional textbooks place strong emphasis on numerical problem solving (often, the numerical problems at the end of the chapter are three to four times as numerous as conceptual questions), while many of the nontraditional curricula increase emphasis on building conceptual understanding, with less attention given to numerical problem solving.

Effective teaching statements: Significant differences

The next largest difference was observed in instructors' views of textbooks. While 17% of traditional instructors strongly agree that a textbook is an important course tool, none of the nontraditional instructors strongly agree with this statement. Again, this is not a surprising statement when we recognize that many instructors who plan use of a textbook may present topics in the same order as the textbook, and many nontraditional pedagogies downplay or eliminate the role of the traditional textbook (see, for example, Cooney et al., 2007; Hestenes, 1987).

Although large numbers of both traditional and nontraditional instructors view group work as an important element of effective physics teaching, nontraditional instructors are much more likely to strongly agree about the importance of group work. Again, this is consistent with reform pedagogies' emphasis on working in groups to build understanding.

Finally, traditional instructors had a tendency to agree more than the nontraditional instructors with the statement regarding the importance of clear directions prior to beginning laboratory work. Only 6% of traditional instructors disagreed with this statement to one degree or another, compared with 17% of the nontraditional instructors. This seems consistent with the role laboratory investigations play in physics classrooms. In many traditional physics courses, laboratory investigations usually follow the establishment of theory, and students are given clear step-by-step directions (i.e. "cookbook" labs) in an attempt to ensure the careful collection of appropriate data (Clough, 2002; Lochhead & Collura, 1981; Luckie et al., 2004; Roth, 1991; Royuk & Brooks, 2003). By contrast, many nontraditional approaches espouse moving laboratory investigations to the beginning of units of study and require students to establish their own experimental procedures and draw meaning from their observations (Hestenes, 1987).

Although the difference is only mildly statistically significant, traditional instructors are more likely to agree that it is important to answer most student questions. One third of nontraditional instructors disagree with this statement to some extent, compared with only 14% of traditional instructors, and no traditional instructors strongly disagree. Again, this result might be anticipated since many nontraditional approaches encourage or require Socratic dialogue (Hake 1992), where questions are used to help the student build their own ideas, but few student questions are directly answered by the instructor.

Developing the ability to work in a group ranks highest overall for all teachers, and the ability to draw sketches or diagrams ranks last. Other high-ranking abilities include answering conceptual questions, graphing and interpreting data, and making measurements and collecting data. Interestingly, the statement “knowledge of physical laws and/or formulas” ranked eighth overall, and one could likely mount a reasonable argument that understanding physical laws should be a core value in a physics class. (We note, however, that a respondent could conceivably view all of the skills and abilities as important, so an item at the bottom of the list should not be interpreted as necessarily being unimportant.)

Rankings: Significant differences

We observed highly significant statistical differences only two times when comparing the two groups’ rankings of individual statements.

The first observed significant difference was in response to the statement, “the ability to graph and interpret data.” Overall, this ranks second for nontraditional instructors (with an average ranking of 3.97) and sixth for traditional instructors (with an average ranking of 5.57.) This aligned with our expectations, as the second most popular inquiry approach used by our surveyed teachers, modeling (40% of nontraditional teachers report using this method), requires students to graph data and develop appropriate mathematical models (Hestenes, 1987).

The second observed significant difference was in response to the the statement “the ability to algebraically manipulate physics equations and solve numerical problems.” This statement was ranked highest overall by traditional physics teachers (average ranking = 3.95), while it ranked sixth by nontraditional physics teachers (average ranking = 5.64.) This is perhaps not surprising, given inquiry-based approaches’ downplay of traditional “plug-and-chug” problems. This feature, however, may contribute to these approaches being viewed suspiciously by those who value a physics course for teaching students to solve numerical problems.

Marginally significant differences were observed between group rankings of four statements: “the ability to read a textbook for understanding,” “knowledge of physical laws and/or formulas,” “the ability to communicate scientific ideas verbally,” and “the ability to draw sketches or diagrams.” On average, the first two statements ranked higher with traditional teachers, while the latter two statements ranked higher with nontraditional teachers. We view some of these results as consistent with our expectations. Instructors who use inquiry-based approaches are typically less dependent on a textbook, and when one is used, it is often in workbook form that requires students to fill in much of the information after experimentation or discussion. Likewise, these same teachers might value student explanations and require student conversations more than traditional teachers. However, unless the word “formulas” possesses negative connotations for nontraditional teachers, we see no obvious reason for them to rank student knowledge of physical laws lower than their traditional colleagues, and we frankly were surprised at the overall low rankings assigned to that statement by all teachers. Similarly, we can think of no reason why one group of teachers might value sketching and diagramming abilities less than another.

Differing views

While there are limited inferences one can draw from the two questions discussed without further research, the areas where clear differences are seen between traditional and nontraditional teachers' views are suggestive.

Nontraditional teachers are more likely to be open to the idea of physics first, though perhaps it is more appropriate to say they are more neutral or less negative on the topic, as only small minorities of each group agreed or strongly agreed with the atypical sequence. This suggests two things: schools or districts interested in implementing a physics first program might be best served to seek out instructors who have experience with nontraditional approaches to teaching physics, as the approaches are perhaps better suited for a ninth-grade population, and the instructors are likely to be less negative about the prospects for success. Secondly, with the majority of teachers in both groups neutral on or opposed to the idea, additional research on successful implementation is needed, though this has recently begun (Liang et al., 2012; O'Brien & Thompson, 2009.) Teacher buy-in is crucial to the success of any educational innovation (Turnbull 2002), and evidence of success with physics first would likely be important in helping convince skeptical instructors that early physics courses work.

On our survey, traditional teachers view textbooks as a more important tool than do their nontraditional counterparts, as one might expect. This suggests that teachers who employ nontraditional pedagogies are using textbooks less in their courses (or at minimum see the role or a text as secondary), and should contribute to an important discussion and research agenda: what is the role of a physics textbook? Should texts be used in high school physics classes, or is this fundamentally detrimental to the learning of physics? More broadly, what are the goals of a high school physics course, and should the development of the ability to read a scientific book be part of these goals?

On a related topic, nontraditional teachers place less importance on numerical problem solving. While a handful of studies at the university level have shown that students participating in more conceptually-oriented classes perform as well at quantitative problem solving as control groups (Crouch & Mazur, 2001; Hake, 1997), we find no work that specifically addresses this issue in a high school physics environment. Again this raises an interesting question: should quantitative problem solving be a primary goal of a physics course, or is it superseded by other goals, such as the development of conceptual understanding of physics?

Both nontraditional and traditional teachers value group work, but nontraditional teachers see it as even more important to their physics classes. To us, this also suggests two points: one, if schools value nontraditional approaches, they need to make sure that spaces devoted to physics classes are designed to facilitate effective group learning (difficult in a lecture-hall type environment or classroom with fixed, forward facing desks). Second, effective facilitation of groups needs to be an important part of pre-service and in-service teacher training programs (Springer et al., 1999.)

While we have demonstrated clear differences in the views of traditional and nontraditional physics teachers in several areas relating to physics teaching and learning, we cannot, given the scope of our research, assign causality. It's likely that some of the nontraditional respondents were already predisposed to the methods used in inquiry-style instruction, and this led them to seek out modes of instruction that correlated with their existing teaching philosophy. For others, it's likely that the experience of using nontraditional approaches has shifted their views on effective teaching. Still others probably undergo some combination of the two. Regardless, the teachers we dubbed nontraditional have (on average) views of teaching more in line with style of instruction called for by state and national standards (National Research Council, 1996; Iowa Department of Education, 2008), suggesting that expanding opportunities for teachers to learn and teach using nontraditional methods of instruction is important to science education reform.

Conclusions

We designed a survey intended to give us a picture of high school physics teachers and teaching in the state of Iowa. A small part of that survey included questions that probed teachers' views on effective physics teaching and the skills they viewed as most important for their students to develop. When we divided the survey respondents into two groups – labeled nontraditional or traditional based on whether or not they reported having used one or more inquiry-based methods of instruction – we observed differences in the views of the two groups on approximately half of the statements. In each case where differences were observed, they coincided with our hypotheses, though in some cases no differences were found where we expected to observe them.

Our findings have several limitations. First and foremost, we used the responses from a single question to divide the teachers into two groups, and made no effort to ascertain the degree to which teachers labeled as nontraditional employed inquiry-based instructional methods in their classrooms. Second, our sample was not random (all known physics teachers were invited to participate), and because of the relatively low population of our state, the number of respondents was rather small. Third, our method of data collection has the possibility of introducing sampling bias toward younger respondents, though reported teaching career lengths makes a strong bias seem unlikely. Likert scale statements, which we used for one question, are categorical as opposed to continuous, and are subject to the interpretations of the reader when deciding one's level of agreement.

These limitations suggest avenues for future research. For example, with additional background questions one might further divide the nontraditional group based on frequency of use (or length of use) of inquiry approaches and examine response patterns for any differences between subgroups. Additionally, the topics investigated by many of our statements could warrant a series of follow up questions and/or observations, both for reliability testing and to allow respondents to further explain their interpretations of our statements.

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