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Clickers as Data Gathering Tools and Students' Attitudes, Motivations, and Beliefs on Their Use in this Application

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Abstract

Members of the Center for Astronomy Education (CAE) and the Conceptual Astronomy and Physics Education Research (CAPER) Team at the University of Arizona have conducted a systematic investigation into the use of wireless, electronic personal response systems (PRS), more commonly known as "clickers," to gather research data in the large enrollment introductory astronomy course for nonscience majors (Astro 101). We describe a study and data, which support the assertion that clickers can be used as a data gathering tool for conducting "real-time" research on student learning in the classroom setting. We also present data suggesting that students believe the use of clickers (1) is beneficial to their understanding of course concepts; (2) contributes to improving their exam grades; and (3) increases their interest in course topics *even* when the clickers are being used solely as research data gathering tools rather than the more traditional application in which clickers are used as an instructional device to gather student votes as part of Think-Pair-Share (TPS) or Peer Instruction (PI). Additionally, we offer a description of our classroom observations, which suggests that the use of color-coded A, B, C, D, E voting cards for gathering student answers in class may hold greater pedagogical value and provide a greater potential to gather accurate research results than do the use of clickers or Scantron™ forms.

1. INTRODUCTION

There is no doubt that in the college teaching community, the use of wireless, electronic personal response systems (PRS), also known as clickers, is becoming more popular year by year. This growing interest and awareness is evidenced by the dramatic increase in (1) articles written about clickers; (2) special sessions and presentations at national meetings of the American Astronomical Society, American Association of Physics Teachers, and Society of College Science Teachers devoted to the use of clickers; and (3) clicker use being part of science education seminars at universities (Dokter *et al.* 2004; Duncan 2006a, 2006b; Lasry 2008; Len 2006; Prather *et al.* 2006; Rudolph 2007). Professional development workshops and publications are widely available that help instructors learn about the implementation of Think-Pair-Share (TPS) and Peer Instruction (PI); that help instructors understand the subtle pedagogical underpinnings on the use of clickers; and that provide questions that can be used in the classroom with this technology (CAE 2008; Crouch and Mazur 2001; Duncan 2005; Green 2002; Mazur 1996; Owens *et al.* 2002; Slater and Adams 2002).

As science education researchers actively involved in both teaching and evaluating the effectiveness of instruction in astronomy, we were interested in determining if clickers could be used as an effective and reliable research data gathering tool that could serve as a viable alternative to the more traditional, computer-graded, Scantron™ forms for data collection. While Scantron™ forms and clickers are both capable of accurately receiving and recording hundreds of student responses, the clickers are much easier to use on a daily basis, and require a fraction of the time to accomplish the same task. There is a very important point to be made here, namely, that this real-time, in the classroom ability of clickers to receive and analyze the student responses is incredibly enticing for the purposes of teaching and learning *and* for the purpose of conducting research.

To establish the reliability of clickers in this context, we designed an investigation to reproduce an earlier study (Prather *et al.* 2005). That study demonstrated how an innovative learner-centered instructional approach using *Lecture-Tutorials for Introductory Astronomy* (Prather *et al.* 2008) substantially improved students' understanding of core topics commonly taught in the introductory college astronomy course for nonscience majors (hereafter referred to as Astro 101) beyond what was achieved from lecture alone. In the previous study, all student data were gathered twice, once postlecture (PL) and again post-lecture-tutorial (PLT) using a separate Scantron™ form for each student and for every topic covered in the study throughout the course of the semester. The critical distinction between the current study and the previous study is that, in the previous study, all precourse, postlecture, and post-*Lecture-Tutorial* data were laboriously gathered using student-completed Scantron™ forms. In the current study, however, all PL and PLT data were collected and initially tabulated in real-time in the classroom using the clickers, where each student had an individual, but anonymous, clicker unit they used to submit their answers.

At this point we would like to re-emphasize that during this current research study, the PRS, or clickers, were not used as a teaching tool as part of TPS or PI, but rather as the equivalent of an electronic Scantron™ bubble form. We did not have students discuss their ideas or answers with each other at any time, nor was class time spent on having a discussion about the questions or answers used in the study until after all data were collected. Rather, students voted simultaneously and anonymously to the conceptually challenging multiple-choice questions provided after traditional lecture and then again after completing a collaborative *Lecture-Tutorial* activity on the day's topic—without feedback or credit for their answers. Only then would the instructor engage students about the answers they had provided, but student-student discussion and further voting on the questions posed was not part of the implementation.

In addition to testing the efficacy of clickers as a data gathering tool for conducting education research on students' gains in understanding, we were also interested in determining the degree to which students' motivations and beliefs about learning astronomy were impacted by our implementation of clickers as a research tool rather than as an instructional technology. This avenue of research points to an interesting outcome that should bolster one's choice to implement clickers in the classroom. We believe that students would not comment favorably on the use of Scantron™ forms as a source of motivation to work harder, or to attend class more frequently, or as an aspect of the course that contributed to their understanding. We were, however, quite curious about how students' responses might be different on these outcomes as a result of the game-show mentality and sense of play that is fostered with the novelty of clickers (Gerace *et al.* 1999; Len 2006; Pintrich 2002; Pintrich, Marx, and Boyle 1993).

2. RESEARCH QUESTIONS AND METHODOLOGY

The following two research questions were then used to motivate this current research project:

1. Can clickers serve as reliable and valid data gathering tools as compared with the use of Scantron™ forms for conducting education research?
2. To what extent do students believe the use of clickers enhances their learning of course concepts, their interest in course topics, their engagement in *Lecture-Tutorials*, and their class attendance even when used solely as a data gathering tool?

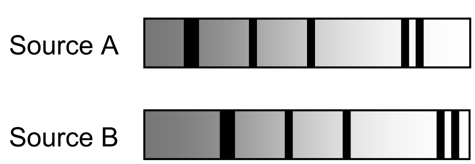
The data needed to answer our research questions were gathered during a single semester of an Astro 101 course taught at a school with *The Carnegie Classification of Institutions of Higher Education*™ designation of RU/VH: Research Universities (very high research activity). The participants were the approximately 250 students enrolled in this Astro 101 course. The overwhelming majority of students were nonscience or undecided majors. Prior research has shown that the demographics of Astro 101 classes are similar to demographics of their host institutions (Deming and Hufnagel 2001). The 300-student lecture hall/classroom in which this study took place was equipped with traditional auditorium seating, bolted-down chairs with small flip-up desks, a computer and projection system at the front of the class, and a PRS utilizing 300 radio frequency clickers and two receivers capable of recording the responses for all students in approximately 10 s. Classes were held three times per week for 50 min, with no additional discussion, recitation, or laboratory sections. The course instruction and data collection were run by one instructor and two teaching assistants. Students were instructed on how to use the clickers during the first week of the course. Student data were collected with the clickers almost every class meeting during the semester, making their use a familiar aspect of the course. For each class meeting, students picked up a clicker as they entered the classroom, and then returned it as they exited at the end of class.

Specific responders were not assigned to individual students, nor did students submit a code before responding to identify themselves; thus, all voting was completely anonymous and students received neither grades nor any credit for answering questions. This highlights a difference from the use of Scantrons™ in the initial study because students wrote their names and identification numbers on their individual Scantron™ forms. Moreover, this implementation differs from the more common clicker implementations in which students typically purchase their own responder, or are assigned a specific institution-owned responder at the beginning of the course, and/or input a personal identification number before voting on an answer each day in class (Duncan 2005). In all of these more typical scenarios, responses are associated with individual students' identities, as compared with the completely anonymous use of clickers in this study.

Nearly every class meeting was divided between short lectures (20–25 min), learner-centered activities (*Lecture-Tutorials*; 15–20 min), and PRS questions (5–10 min). As with the prior research (Prather *et al.* 2005), the first day of class was fundamentally different in that students were given half of the 68 assessment questions administered in the original study (as either a Form A or a Form B; each containing 34 questions), which were designed specifically to measure students' understanding of concepts to be presented that semester. Their answers were recorded on Scantron™ forms and served as the "precourse" data for this study.

In subsequent class meetings, students were asked the relevant subset of the multiple-choice assessment questions covering that day's topic, and their answers recorded by using clickers to assess their conceptual understanding directly after receiving a traditional lecture on a particular concept. The students then engaged in completing a *Lecture-Tutorial* activity based on that particular day's learning objective(s) while working in collaborative pairs. During this time, the instructor and TAs served as facilitators and helped guide students' learning, as needed. After the *Lecture-Tutorial* activity was completed, and student questions regarding these activities had been discussed, students were again asked a subset of the multiple-choice assessment questions with their answers recorded by using the clickers. By comparing the class responses to these conceptually challenging, multiple-choice assessment questions immediately after lecture, and again after completion of the *Lecture-Tutorial*, it was possible to measure the degree to which students' understanding of the course concept increased as the result of each form of instruction.

You observe two spectra (shown below) that are redshifted relative to that of a stationary source of light. Which of the following statements best describes how the sources of light that produced the two spectra were moving? Assume that the left end of each spectrum corresponds to shorter wavelengths (blue light) and that the right end of each spectrum corresponds to longer wavelengths (red light).



1. Source A is moving faster than source B.
2. *Source B is moving faster than source A.*
3. Both sources are moving with the same speed.
4. It is impossible to tell from looking at these spectra.

Figure 1. PRS question probing understanding of Doppler shift

Again we would like to make the critical point that students were not shown the results of their voting nor the correct answers to the conceptual questions after their postlecture voting, nor were they asked to discuss their ideas or answers with other students. Students were only shown the correct answer, and the summarized distribution of all student responses, *after* voting with the clickers for the final time following the completion of the *Lecture-Tutorial*. Figure 1 contains an illustrative example of a typical conceptually challenging multiple-choice assessment question that students voted on with the clickers as part of this study.

To investigate the answer to the second research question, students were given a 19-item survey at the mid-point of the semester, ten items asked about specific components of the course and how those components contributed to (1) their understanding of course concepts, (2) how well they do on exams, (3) their interest in course topics, and (4) their participation in *Lecture-Tutorials*. The remaining nine items asked them about motivations for coming to class and about demographics. The analog scale used to assess how strongly students believed specific components of the course contributed to the above areas provided students with five choices, A–E with the end points marked as "not very much" to "very much." Data were collected conventionally with Scantrons™. The instrument is included in the Appendix.

3. RESULTS

Table 1 summarizes the averaged results for the aggregated 68-item multiple-choice question inventory used in this study. The average score from student responses on the first day of class was 25% correct. Following the lecture portion of the class, the average score across all questions rose significantly to 62%. After students

Table 1. Precourse, postlecture, and post-*Lecture-Tutorial* content test results

	Pre-course	Post-lecture	Post-*Lecture-Tutorial*
% correct	25%	62%	80%
Participants	$N_{\text{Form A}}=132$, $N_{\text{Form B}}=49$	$N\sim182$	$N\sim177$

completed the *Lecture-Tutorial*, the average score increased significantly to 80%. All three differences are significant at the $p<0.05$ level, as determined by a t-test for related samples.

A direct comparison of results presented from Prather *et al.* (2005)—precourse: 30%; postlecture: 50%; post-*Lecture-Tutorial*: 72%—reveals that students' postlecture and post-*Lecture-Tutorial* correct answer averages to these questions is similar in this study. This result provides compelling evidence that clickers are as effective at gathering student data as Scantron™ forms.

For the second part of our investigation using the 19-item analog-scale survey, we collected $N=219$ surveys (with results recorded on Scantron™ forms), although not all items were completed by all students, item response rates ranged from $N=210$–218. (The Appendix provides a full copy of the survey including the response distributions.) To explore the possibility of gender specific responses in our data, we disaggregated the data according to gender, and performed a X^2 test to check for statistically significant differences in responses between males and females. There were no significant gender biases in the responses insofar as the instrument could detect.

As one method of analysis, student responses to the 19-item survey were "binned" together into two bins: responses C, D, and E coded as favorable responses in one bin, and responses D and E coded as most favorable responses in the second bin. Table 2 summarizes the survey results after being binned in this way. Note that the word "responders" was used in this survey in place of the word "clickers." For this reason we will use responder in the data table and analysis below.

Table 2. Results of the mid-semester survey

Question domain	Favorable responses (C, D, and E) (%)	Most favorable responses (D and E) (%)
1. *Contributes to learning course concepts:*		
Responders	85	60
Lecture-Tutorials	95	84
Lecture alone	84	62

Question domain	Favorable responses (C, D, and E) (%)	Most favorable responses (D and E) (%)
2. *Contributes to achievement on course exams:*		
Responders	73	45
Lecture-Tutorials	95	78
Lectures alone	85	54
3. *Contributes to interest in course topics:*		
Responders	71	40
Lecture-Tutorials	87	46
Lecture alone	84	57
4. *Contributes to course attendance:*		
Responders	47	28
Lecture-Tutorials	78	52
Lectures alone	82	60

Table 2. (*Continued.*)

Several interesting points can be inferred from these results. Students reported that the use of responders (clickers) contributed positively to their learning of course topics, achievement on exams, interest in course topics, and, to a lesser extent, attendance. We were interested to find that students reported that the *Lecture-Tutorials* were the aspect of the course that helped them most in learning the course concepts and doing well on course exams. Students also reported that the lectures contributed most to their interest in course topics and attendance. Additional results that are not summarized in Table 2, but are available in the Appendix, show that 76% of students reported that they tried harder to understand *Lecture-Tutorials* content so that they would get the correct answers on the conceptual questions after completing the *Lecture-Tutorial* activities (Q5), with 49% of students choosing the most favorable responses. This indicates that answering the questions correctly was a source of motivation for students to work harder on the *Lecture-Tutorial* activities, which is a positive outcome since the *Lecture-Tutorials* have previously been shown to improve learning (Prather *et al.* 2005). It is worth noting that the low response level on the category "Contributes to Course Attendance" relating to the use of clickers is likely due to the absence of grade incentives provided to students for voting with the clickers, combined with their use as data gathering devices rather than instructional tools.

These results suggest that the use of clickers as data gathering tools (and as a type of formative assessment to students) positively contributes to students' attitudes and beliefs about their learning, which is consistent with the metacognition and motivation literature (Bransford *et al.* 1999; Brissenden *et al.* 2001; diSessa *et al.* 2003; Sinatra and Pintrich 2003). However, this positive result (concerning the use of clickers) occurs at a lower level, in every category, than the students' responses to the use of *Lecture-Tutorials*, which were the primary instructional strategy implemented in the classroom environment studied. Due to this instructional focus on *Lecture-Tutorials* over clickers, we interpret these results as illustrating that students are aware of the impact different elements of the instruction have on their learning and beliefs, in particular those that promote intellectual engagement. These results also suggest that publications reporting the positive attitudes of students regarding the use of clickers may be more reflective of (1) their application in Think-Pair-Share or Peer Instruction instructional approaches, or (2) the incentives given toward student grades from in-class quizzes or credit for participation, over the use of the clicker technology in and of itself (Duncan 2005; Kaleta and Joosten 2007; Lasry 2008; Len 2006; Rogers and Starrett 2006). This assertion is further supported by noting, with respect to their "likeliness to attend class," that students ranked highest the only in-class elements probed by the survey, which actually earned them points toward their grades (i.e., in-class participation, in-class homework) over the lecture, clickers, and *Lecture-Tutorials* (see Table 2).

4. DISCUSSION

There are several important results that emerge from this study on the use of clickers as data gathering devices. First, collecting research data in the classroom, in real-time, with clickers produced statistically consistent results compared with the use of Scantron™ forms, but was far more efficient as a data gathering method. Second, students reported that clickers contributed positively to their learning of course concepts and to their success on exams—even when the clickers were used as a data gathering tool, rather than as an instructional technology coupled to an interactive learning strategy. Third, the use of clickers seemed to serve as a motivational tool in the classroom since students reported that their use positively impacted their interest in course topics and the attention they paid to material presented in class. Adding weight to our conclusions, students anecdotally provided information that illustrated they believed the use of clickers helped them diagnose their own learning. We feel it is critical to note that while the survey instrument questions were designed to highlight the use of "responders," it is impossible to completely separate students beliefs about the clickers from their beliefs about the questions used with the responders, and their desire for feedback on their voting (which was only provided post-*Lecture-Tutorial* and which they never received when Scantron™ forms were used).

In subsequent semesters we have continued to ask the same research questions after the students complete the *Lecture-Tutorials* as a way of offering students a self-check on their understanding of the topic taught. Though further research is needed, we have anecdotally observed two dramatic increases that happened simultaneously. We have seen a positive shift in the number of correct answers provided by students in their voting after completing the *Lecture-Tutorials* beyond what is reported here or in the previous study (Prather *et al.* 2005). Further, we have observed an increase in the percentage of students choosing to vote during the polling sessions. We consistently have nearly all students voting every time, on every question. We believe this impressive response is coupled to, and explained by, one simple change in the way we have students vote. We now have students use color-coded A, B, C, D, E voting cards instead of clickers, though still simultaneous and anonymous. We believe when students know you know what they are voting in real-time (because you can see them, and they know that), they all vote. Also, we believe, since they know you can see them, they want to display the correct answer in front of them, all spurred on by social/personal motivations which neither the use of clickers nor Scantron™ forms seem to evoke. Other pedagogically beneficial uses of the color-coded voting cards we have experienced are (1) their ability to provide the instructor with an almost instantaneous, detailed display of the entire classroom distribution of student responses, (2) their ability to provide alternative voting formats—such as showing all colors/letters simultaneously to indicate that the student has no idea which is the correct answer and (3) their ability to provide greater flexibility in question prompting and types of student feedback that can motivate student learning in ways not possible to utilize with clickers.

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Appendix

This appendix consists of the following survey.

Table 3. NATS 102 The Physical Universe: Mid-Semester Responder Survey (Total *N*=219)

1.	I am__	
	Male	Female
	121 students	96 students
	55%	44%

Table 3. (*Continued.*)

2.	What grade do you think you will receive in this course?				
	A	B	C	D	E
	81	99	33	7	2
	37%	45%	15%	3%	1%
3.	Does knowing you will be using the **responders** following lecture cause you to pay more attention to the material presented in the lecture?				
	A	B	C	D	E
	Not very much				Very much
	31	35	61	70	18
	14%	16%	28%	32%	8%
4.	To what extent do you believe the use of **responders** improves your learning of the course concepts?				
	A	B	C	D	E
	Not very much				Very much
	11	20	55	83	48
	5%	9%	25%	38%	22%
5.	To what extent do you try harder to understand the **Lecture-Tutorial activities** so that you will get the correct answers on the responder questions after the activities?				
	A	B	C	D	E
	Not very hard				Very hard
	18	35	57	70	39
	8%	16%	26%	32%	18%
6.	To what extent do you believe the use of **responders** contributes to how well you do on class exams?				
	A	B	C	D	E
	Not very much				Very much
	24	35	61	72	26
	11%	16%	28%	33%	12%
7.	To what extent do you believe the use of **responders** contributes to your interest in course topics?				
	A	B	C	D	E
	Not very much				Very much
	24	37	68	66	22
	11%	17%	31%	30%	10%
8.	To what extent do you believe the **Lecture-Tutorial activities** improve your learning of the course concepts?				
	A	B	C	D	E
	Not very much				Very much
	2	9	24	66	118
	1%	4%	11%	30%	54%

Table 3. (*Continued.*)

9.	To what extent do you believe the **Lecture-Tutorial activities** contribute to how well you do on class exams?				
	A	B	C	D	E
	Not very much				Very much
	2	9	37	66	105
	1%	4%	17%	30%	48%
10.	To what extent do you believe the **Lecture-Tutorial activities** contribute to your interest in course topics?				
	A	B	C	D	E
	Not very much				Very much
	9	42	90	68	33
	4%	19%	41%	31%	15%
11.	To what extent do you believe the **lectures alone** (not including the use of responders or the Lecture-Tutorial activities) improve your learning of the course concepts?				
	A	B	C	D	E
	Not very much				Very much
	4	24	48	83	53
	2%	11%	22%	38%	24%
12.	To what extent do you believe the **lectures alone** (not including the use of responders or the Lecture-Tutorial activities) contribute to how well you do on class exams?				
	A	B	C	D	E
	Not very much				Very much
	9	20	70	77	39
	4%	9%	32%	35%	18%
13.	To what extent do you believe the **lectures alone** (not including the use of responder or the Lecture-Tutorial activities) contribute to your interest in course topics?				
	A	B	C	D	E
	Not very much				Very much
	9	22	59	72	53
	4%	10%	27%	33%	24%
To what extent does the item listed contribute to your **likeliness to attend class**?					
14.	The use of responders				
	A	B	C	D	E
	Not very much				Very much
	66	46	42	37	24
	30%	21%	19%	17%	11%
15.	The Lecture-Tutorial activities				
	A	B	C	D	E
	Not very much				Very much
	18	26	57	57	57
	8%	12%	26%	26%	26%

Table 3. (*Continued.*)

16.	The in-class homework				
	A	B	C	D	E
	Not very much				Very much
	13	9	33	53	105
	6%	4%	15%	24%	48%
17.	The in-class participation assignments				
	A	B	C	D	E
	Not very much				Very much
	7	11	35	59	103
	3%	5%	16%	27%	47%
18.	The lectures				
	A	B	C	D	E
	Not very much				Very much
	13	22	48	77	55
	6%	10%	22%	35%	25%
19.	Do you attend this class more often than you attend your other classes?				
	Yes	No			
	131	70			
	60%	32%			

References

Bransford, J. D., Brown, A. L., and Cocking, R. R., eds. 1999, *How People Learn: Brain, Mind, Experience, and School*, Washington, DC: National Academies Press.

Brissenden, G., Slater, T. F., Mathieu, R., and Nise College Level-One Team. 2001, "The Role Of Assessment In The Development Of The College Introductory Astronomy Course: A "How-To" Guide For Instructors," *Astron. Educ. Rev.,* 1, 1.

Center for Astronomy Education (CAE) 2008, http://astronomy101.jpl.nasa.

Crouch, C. H., and Mazur, E. 2001, "Peer Instruction: Ten Years of Experience and Results," *Am. J. Phys.*, 69, 970.

Deming, G., and Hufnagel, B. 2001, "Who's Taking ASTRO101?" *Phys. Teach.*, 39, 368.

diSessa, A. A., Elby, A., and Hammer, D. 2003, "J's Epistemological Stance and Strategies," in *Intentional Conceptual Change*, eds. G. Sinatra, and P. Pintrich, Mahwah, NJ: Lawrence Erlbaum, 237.

Dokter, E. F., Brissenden, G., Prather, E. E., and Slater, T. F. 2004, "The Use and Impact of Personal Responder Devices in ASTRO 101," *Bull. Am. Astron. Soc.,* 36, 681.

Duncan, D. 2005, *Clickers in the Classroom: How to Enhance Science Teaching Using Classroom Response Systems*, San Francisco, CA: Pearson Education Inc.

Duncan, D. K. 2006a, "Success and Failure Using Student Response Systems: 'Clickers,'" *Bull. Am. Astron. Soc.,* 38, 948.

Duncan, D. 2006b, "Clickers: A New Teaching Aid with Exceptional Promise," *Astron. Educ. Rev.,* 5, 70.

Gerace, W. J., Dufresne, R. J., and Leonard, W. J. 1999, *Using Technology to Implement Active Learning in Large Classes*, Arlington, VA: National Science Foundation, ERIC Document Reproduction Service No. ED471419.

Green, P. J. 2002, *Peer Instruction for Astronomy*, Upper Saddle River, NJ: Prentice Hall.

Kaleta, R., and Joosten, T. 2007, “Student Response Systems: A University of Wisconsin System Study of Clickers,” *Educause Center for Applied Research Research Bulletin, 2007*, 1.

Lasry, N. 2008, “Clickers or Flashcards: Is There Really a Difference?” *Phys. Teach.*, 46, 242.

Len, P. M. 2006, “Different Reward Structures to Motivate Student Interaction with Electronic Response Systems in Astronomy,” *Astron. Educ. Rev.,* 5, 5.

Mazur, E. 1996, *Peer Instruction: A Users Manual*, Upper Saddle River, NJ: Prentice Hall.

Owens, D. T., Demana, F., Abrahamson, A. L., Meagher, M., and Herman, M. 2002, *Developing Pedagogy for Wireless Calculator Networks—and Researching Teacher Professional Development*, Final Report. Part 2—Technical Report and Research Description, Washington, DC: National Academy Press, ERIC Document Reproduction Service No. ED479499.

Pintrich, P. R. 2002, “The Role of Metacognitive Knowledge in Learning, Teaching, and Assessing,” *Theory Pract.,* 41, 219.

Pintrich, P. R., Marx, R. W., and Boyle, R. A. 1993, “Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change,” *Rev. Educ. Res.,* 63, 167.

Prather, E. E., Slater, T. F., Adams, J. P., Brissenden, G., and CAPER 2008, *Lecture-Tutorials for Introductory Astronomy*, 2nd Ed., San Francisco, CA: Pearson Education, Inc.

Prather, E. E., Slater, T. F., Brissenden, G., and Dokter, E. F. 2006, “To Click or Not to Click is Not the Question: How Research with Clickers Develops a Better Understanding of When Learning Happens in Your Classroom,” *Bull. Am. Astron. Soc.,* 38, 948.

Prather, E. E., Slater, T. F., Adams, J. P., Bailey, J. M., Jones, L. V., and Dostal, J. A. 2005, “Research on a Lecture-Tutorial Approach to Teaching Introductory Astronomy for Non-Science Majors,” *Astron. Educ. Rev.,* 3, 122.

Rogers, M. L., and Starrett, D. A. 2006, “Calling All Students…Come In, Students…” in *Tomorrow’s Professor*, ed. R. Reis, http://cgi.stanford.edu/~dept-ctl/cgi-bin/tomprof/posting.php?ID=757.

Rudolph, A. 2007, “Interactive Learning and ‘Clickers’,” *Bull. Am. Astron. Soc.,* 38, 949.

Sinatra, G. M., and Pintrich, P. R. 2003, “The Role of Intentions in Conceptual Change Learning,” in *Intentional Conceptual Change*, eds. G. Sinatra, and P. Pintrich, Mahwah, NJ: Lawrence Erlbaum, 1.

Slater, T. F., and Adams, J. P. 2002, *Learner Centered Astronomy Teaching: Strategies for ASTRO 101*, Upper Saddle River, NJ: Prentice Hall.

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