Physics instructors' knowledge and use of active learning has increased over the last decade but most still lecture too much

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A survey of 722 physics faculty conducted in 2008 found that many physics instructors had knowledge of research-based instructional strategies (RBISs), were interested in using more, but often discontinued use after trying. Considerable effort has been made during the decade following 2008 to develop and disseminate RBISs in physics as well as change the culture within the physics community to value RBIS use and other forms of student-centered instruction. This paper uses data from a 2019 survey of 1176 physics instructors to understand the current state of RBIS use in college-level introductory physics, thus allowing us to better understand some of the impacts of these efforts on physics instruction. Results show that self-reported knowledge and use of RBISs has increased considerably and discontinuation is now relatively low. However, although the percentage of time lecturing is less than 10 years ago, many instructors still engage in substantial lecturing (i.e., more than one-third of class time). Relatedly, we find that the majority of RBIS use centers on pedagogies designed to supplement a primarily lecture-based classroom rather than pedagogies designed to support a primarily active learning classroom. This suggests that the physics education research community and beyond has done well promoting knowledge about RBISs and inspiring instructors to try RBISs in their courses. But, there is still room to improve. Based on available evidence about effective instructional practices, we recommend that change agents focus on supporting instructors to increase the percent of class time in active learning and to implement higher impact strategies.

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I. INTRODUCTION

The physics education research community has developed many research-based strategies (RBISs) that have been shown to improve student outcomes. A survey of college-level physics instructors conducted in 2008 found that many physics instructors had knowledge of RBISs [1], were interested in using more RBISs in their courses [2], but often discontinued use after trying one or more

RBISs [3]. Considerable effort has been made during the decade following 2008 to develop and disseminate RBISs in physics as well as to change the culture within the physics community to value RBIS use and other forms of student-centered instruction [4]. This paper uses data from a 2019 survey to understand some of the impacts of these efforts on physics instruction.

A. Efforts to increase the adoption and sustained use of research-based instructional strategies in physics

In our 2008 study of physics instructors in the United States, we found that knowledge about RBISs and persuasion about the benefits of RBISs were high [1,2]. Many instructors also had made the decision to use a RBIS and tried implementing it [3]. However, we also found that discontinuation was high, with about $\frac{1}{3}$ of the instructors who tried to use a RBIS discontinuing the use of that RBIS and all other RBISs that we asked about [3]. Thus, we recommended that more attention be paid to supporting instructors during implementation so that they could implement successfully and not discontinue [3,4].

Whether due to these recommendations or for other reasons, in the decade after 2008, change agents have placed additional emphasis on providing support during implementation along with development and dissemination activities. Perhaps the most far reaching of these efforts is the Physics and Astronomy New Faculty Workshop (NFW), recently rebranded the Faculty Teaching Institute (FTI) [5]. The FTI is important because approximately 40% of all new physics faculty in the U.S. attend the workshop each year [6]. In addition to the in-person workshop, beginning in 2015, FTI attendees were given the opportunity to participate in a faculty online learning community (FOLC) [7–10]. The FOLC experience included virtual meetings with a small group of FTI attendees and a facilitator approximately every other week for approximately one year after the FTI. The goal of the FOLC was to provide support for faculty as they attempt to implement RBISs. Discussions are focused on implementation difficulties and successes. Much of the support is provided by the other FOLC participants, but outside experts are also invited if needed. In addition to FOLC use as part of the FTI, FOLCs have been used in other settings to implement RBISs in physics [11,12]. The FOLC is highly valued by the participants. Participants report the FOLC supported them in implementing improved teaching strategies, increased their reflection about teaching, increased their confidence as teachers, increased their knowledge about teaching, benefited their students, and saved them time overall [13].

Another example of efforts to provide more support for instructors implementing RBISs is the Carl Wieman science education initiative (CWSEI) [14]. In the CWSEI model, discipline-based educational specialists are hired to work with faculty to transform courses taught by those faculty [14–18]. These specialists are typically Ph.D.s with special training in RBISs and discipline-based education research. In one study, Wieman *et al.* [14] found that, of the 70 faculty who implemented RBISs as part of the CWSEI, only one discontinued use. They attribute this high continuation to the support offered by the science education specialists. The specialists help faculty customize the RBIS and are also available to help troubleshoot implementation difficulties. As the authors note "Having a knowledgeable person who can minimize the initial challenges of implementation and ensure that RBISs are successful and well received by students when first implemented is an enormous step towards encouraging faculty to embrace the use of RBISs." [14] (p. 3).

B. Cultural changes—RBIS use becoming more valued

In addition to more focus on providing support to instructors during initial use of RBISs, there is also evidence that the expectations for undergraduate STEM teaching in the U.S. have been changing. That is, many national organizations, higher education institutions, and STEM departments, now value the use of RBIS and encourage their faculty to adopt these strategies [19,20]. For example, the recently published effective practices for physics programs guide (EP3) was developed by the American Physical Society and advocates for the use of research-based instructional practices and inclusive pedagogy in physics courses [21].

Given these changes to the way that advocates of RBIS use in physics have focused more on supporting users, as well as the cultural changes in the expectations for physics teaching it is important to revisit our earlier study to better understand the current situation so as to reconsider current change strategies.

II. DATA COLLECTION

The goal of this paper is to compare results of the 2008 survey of physics faculty [1–3] with a more recent 2019 survey of physics faculty. Both surveys were focused on instructors teaching introductory-level physics in the U.S. We describe each survey in the following sections.

Both surveys examined instructional practices in two ways. The first was focused on instructors' knowledge about and use of named RBISs. The second was focused on the amount of class time that instructors spent in active learning.

Data about knowledge and use of named RBISs was collected and analyzed using Roger's' diffusion of innovations theory. Rogers [22] proposes that adoption of a new practice occurs over time in a series of five decision-making stages: Knowledge about the innovation, Persuasion about the benefits of the innovation, Decision to use the innovation, Implementation of the innovation, and Confirmation of continued implementation of the innovation. Thus, as discussed later, instructors were asked questions about whether they knew about specific RBISs, whether they had ever tried them, and whether they currently use them.

Data about the amount of class time that instructors spent in active learning was collected and analyzed by asking instructors to estimate the amount of class time used in various instructional activities. Percentage of class time spent in active learning was taken to be any time that students were not watching the instructor lecture or solve problems.

A. 2008 survey ($n = 722$)

The 2008 survey was developed by two of the authors (Dancy and Henderson) in consultation with researchers at the American Institute of Physics Statistical Research Center. Questions focused on their teaching situation, experience and attitudes toward teaching innovations, their instructional goals and practices and demographic information. Faculty were eligible for the survey if they had taught an introductory quantitative course in the last two years and were full-time or permanent employees (i.e., faculty who were part-time, temporary employees were not eligible for the survey).

The survey was administered in Fall 2008 by the American Institute of Physics Statistical Research Center (SRC). Sampling was done at three types of institutions: (1) two-year colleges (TYC), (2) four-year colleges that offer a physics bachelor's degree as the highest physics degree (BA), and (3) four-year colleges that offer a graduate degree in physics (GRAD). 722 usable responses were collected from instructors at 345 different institutions. The overall response rate was 50.3%.

Further details on the 2008 survey as well as results of analysis can be found elsewhere [1–3].

B. 2019 survey ($n = 1176$)

The 2019 survey was designed, in part, as a follow-up to the 2008 survey. Similar to the 2008 survey, the sample included postsecondary instructors who had taught introductory physics courses, not entirely online, in the previous two years, at two-year colleges (TYC), four-year colleges without graduate degrees in physics (BA), and four-year colleges that offer a graduate degree in physics (GRAD). The 2019 survey also sampled instructors in chemistry and mathematics in addition to physics. Only the physics data is presented here; other findings and more details on survey distribution are discussed elsewhere [23,24].

The 2019 survey was developed by six of us (M. D., C. H., E. J., N. A., M. S., J. R.) for this project. The full survey covered five main topics: (i) course context and details; (ii) instructional practice; (iii) awareness and usage of active learning instruction; (iv) perceptions, beliefs, and attitudes related to students, learning, and departmental context; and (v) personal demographics and experience. A web-based version of the instrument was built and distributed in partnership with the American Institute of Physics Statistical Research Center. Stratified random sampling was done by institution based on institution type, with the goal of developing a representative sample of institution types. Invitations were sent to over 18,000 individuals identified from publicly available information (e.g., institution website) and communication with department chairs by members of the American Institute of Physics Statistical Research Center. The full survey was answered by 3769 instructors of which 1176 were collected from physics instructors at 565 different institutions (1244 were collected from chemistry instructors and 1349 were collected from math instructors).

C. Respondent demographics

Demographics of respondents from the two surveys are shown below in Table I. All demographic identities are self reported except for institution type. Demographics of respondents were similar across both surveys except that the 2019 survey was answered by instructors with slightly more teaching experience. Analysis of the 2008 survey indicated that, of these characteristics, only gender was correlated with knowledge or use of RBIS, with being a woman associated with higher levels of use [3]. Therefore any differences in results are most likely the result of time and not of a different population sampled.

III. RESULTS AND DISCUSSION

In this paper we present three comparisons between the 2008 and 2019 surveys. First, we look at how self-reported

TABLE I. Demographics of survey respondents in 2008 and 2019.

	2008 ($N = 722$)	2019 ($N = 1176$)
Type of institution		
Two year college	25.8%	22.2%
Undergraduate program	35.3%	31.7%
Graduate program in physics	38.9%	46.1%
Academic rank		
Lecturer, instructor, or adjunct	14.3%	21.5%
Assistant professor	20.8%	16.6%
Associate professor	24.2%	22.9%
Full professor	35.6%	36.7%
Other rank	5%	2.2%
Gender		
Woman	17%	21.3%
Man	83%	78.6%
Other gender	n/a	<1%
Semesters taught		
1–4 semesters	15%	5.1%
5–10 semesters	20%	13.3%
>10 semesters	65%	81.6%

knowledge and use of specific Research-Based Instructional Strategies (RBISs) has changed over time. We then compare how overall reports of active learning have changed. Finally, we compare where respondents are in Rogers' innovation decision process in the two surveys.

A. Knowledge and use of specific RBISs have increased between 2008 and 2019

In both the 2008 survey and the 2019 survey, we presented respondents with a list of specific and common RBISs. The 2008 survey asked about 24 RBISs and the 2019 survey asked about 14 with 8 RBISs overlapping both surveys (see Fig. 1 for the 8 overlapping RBISs). In both surveys respondents were presented with an RBIS along with a description of the RBIS (see Appendix for descriptions). Some of the RBISs presented in the 2019 survey were generalized strategies (e.g., group work) in order to facilitate comparison between the three disciplines (chemistry, math, physics) surveyed. Instructors were asked to describe their familiarity and use of each RBIS by selecting from 5 options. These options were slightly different in the two surveys. Table II provides details on the answer choices and how they were organized into knowledge and use categories.

Figure 1 compares levels of knowledge and use reported in 2008 and 2019 for the 8 strategies that were on both surveys (data for all RBISs is presented later).

For every strategy, both knowledge and use levels have greatly increased over the 10 years between surveys. Notably, knowledge levels are generally high, indicating efforts to increase knowledge are likely not the most productive leverage point. In the 2019 survey nearly all instructors report knowledge of multiple RBIS and 98% of instructors report knowing about at least one (compared to 88% in the 2008 survey). Similarly, most instructors (87%) now report using at least one RBIS (compared to 49% in the 2008 survey).

B. The amount of time instructors report lecturing decreased between 2008 and 2019 but is still high

In addition to asking respondents about their knowledge and use of specific RBIS we also asked about the time they utilized particular types of general classroom activities in their teaching. Here we compare the relative time

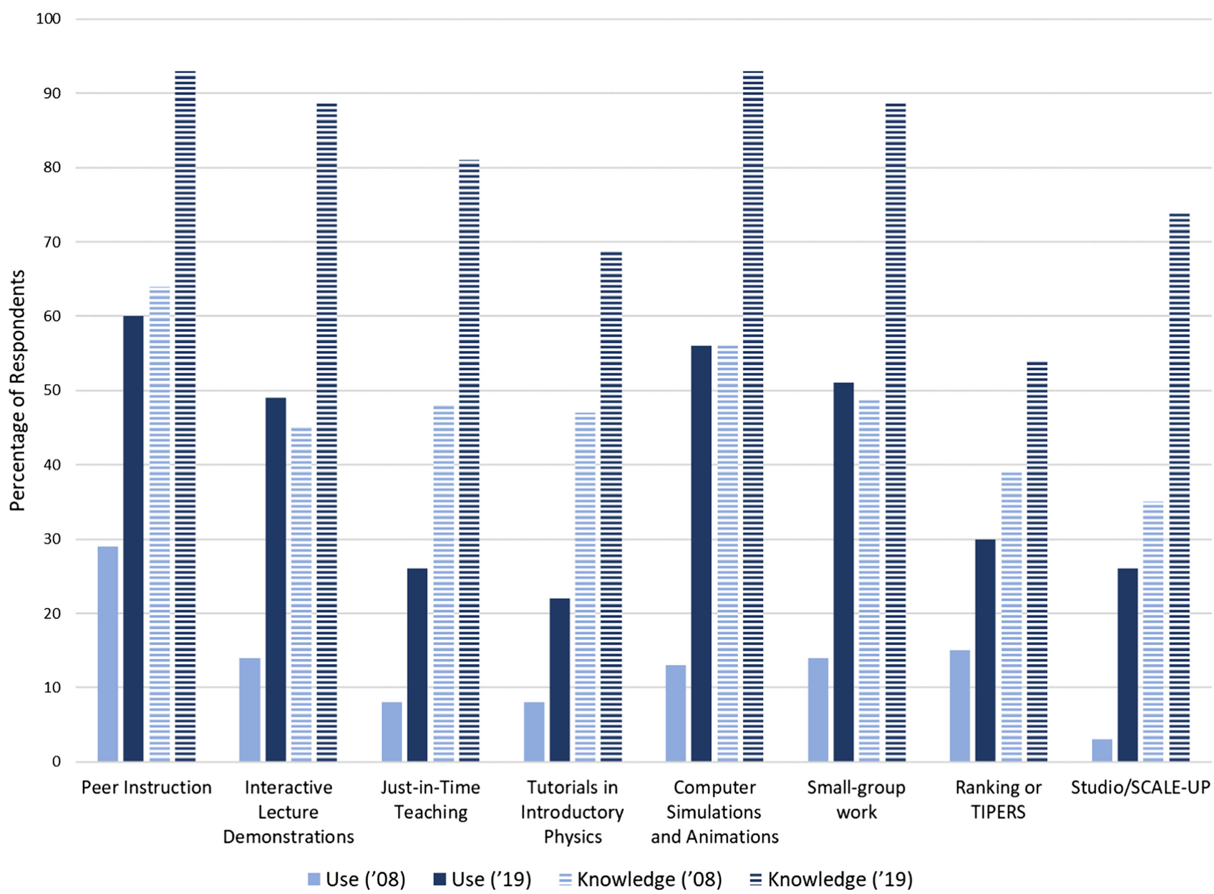

FIG. 1. Comparison of reported knowledge and use of specific RBISs in 2008 and 2019. Respondents are considered to have knowledge if they were classified as either a knowledgeable nonuser or a former user. If a respondent indicated they were a user, they were also counted as being knowledgeable about the RBIS.

TABLE II. Categorization scheme for specific RBIS knowledge and use. Survey respondents were asked to think about a specific introductory course they taught as the primary instructor in order to answer the question.

Categorization in analysis	Roger's (1995) stages	2008 answer choice	2019 answer choice
No knowledge	Knowledge	"I have never heard of it."	"I have never heard of this."
Knowledgeable nonuser	Persuasion decision	"I've heard the name, but do not know much else about it." or "I am familiar with it, but have never used it"	"I know the name, but not much more" or "I know about this, but have never used it in this course."
Former user	Implementation	"I have used all or part of it in the past."	"I have tried it in this course, but no longer use it."
Current user	Confirmation	"I currently use all or part of it."	"I currently use it in this course to some extent."

instructors spend lecturing vs. utilizing active learning techniques. The questions were asked differently on the two surveys as described below.

2008 Survey: Respondents were asked to respond to the question "In the 'lecture portion' of your introductory course, please estimate the percentage of class time spent on student activities, questions, and discussion." They could enter any number into a textbox. This was taken as the percentage of class time spent on active learning.

2019 Survey: Respondents were asked, "What proportion of time during regular class meetings do students spend doing the following?" Answer choices were provided in increments of 5%: working individually, working in small groups, participating in whole-class discussions, listening to the instructor lecture or solve problems. These activities were required to sum to 100%. For the purposes of comparison with the 2008 survey, we take the percentage of class time spent on active learning as the sum of the first three items.

Figure 2 and Table III show a comparison of responses to these two questions on both surveys. Consistent with reports of increasing use of RBISs, we find that reports

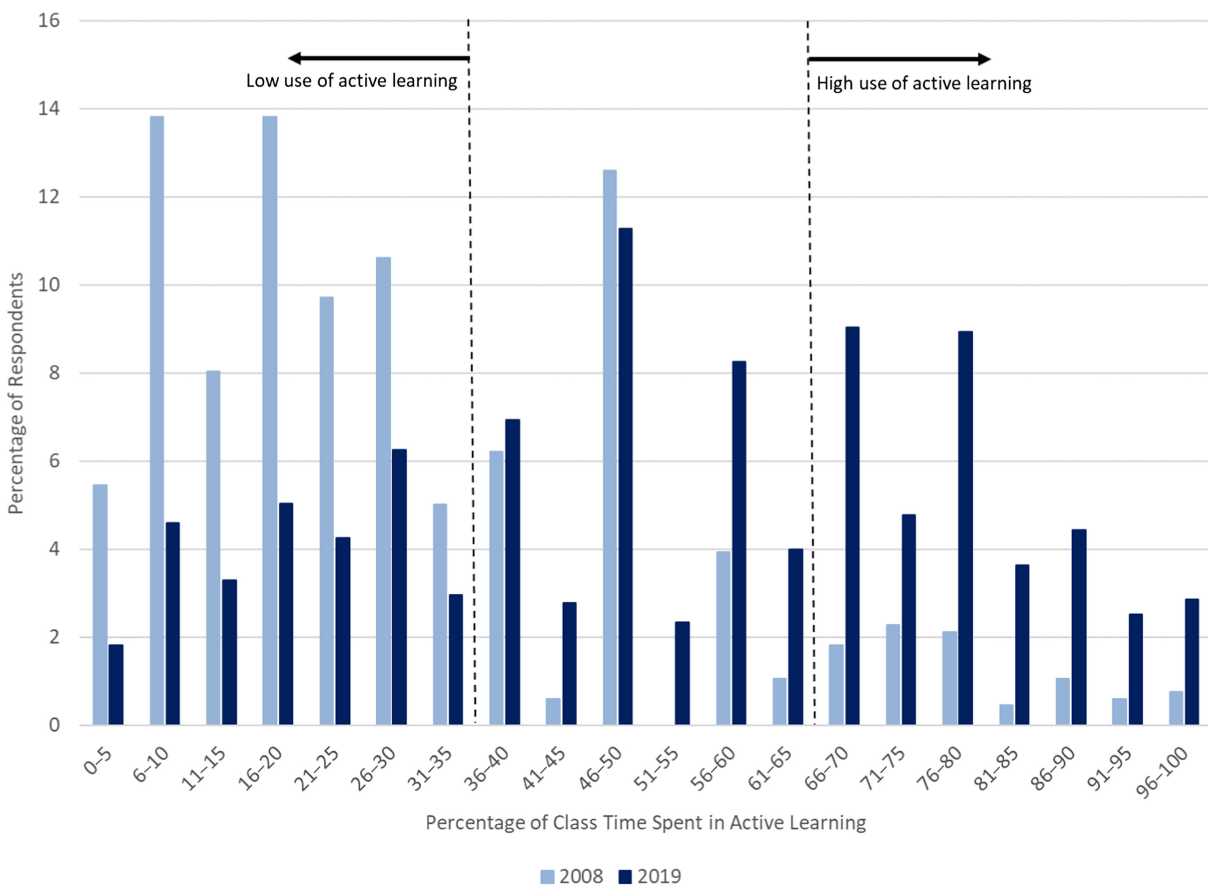

FIG. 2. Comparison of reported time spent on student activities.

TABLE III. Percent of class time reported to be spent in active learning.

% of class time spent in active learning	2008 survey	2019 survey
0–5	5.5	1.8
6–10	13.8	4.6
11–15	8.0	3.3
16–20	13.8	5.0
21–25	9.7	4.3
26–30	10.6	6.3
31–35	5.0	3.0
36–40	6.2	6.9
41–45	0.6	2.8
46–50	12.6	11.3
51–55	0.0	2.3
56–60	3.9	8.2
61–65	1.1	4.0
66–70	1.8	9.0
71–75	2.3	4.8
76–80	2.1	8.9
81–85	0.5	3.6
86–90	1.1	4.4
91–95	0.6	2.5
96–100	0.8	2.9
Low use (35% or less)	66.5	28.5
High use (66% or more)	9.1	36.2

of general active learning use have increased. Of note is that the number of instructors reporting using primarily lecture (i.e., ⅓ or less of class time on active learning, represented as 35% or less in our data table) has fallen by more than half over the years. Conversely, the number of instructors reporting high use of active learning (i.e., ⅔ or more of class time on active learning, represented as 66% or higher in our data table) has more than tripled during this time.

Our findings are consistent with others. For example, Manduca *et al.* [25] found that the percentage of class time that geoscience faculty spent on active learning increased between 2004 and 2012.

Based on survey responses taken between 2015 and 2018, Chasteen *et al.* [6] found that before the New Faculty Workshop, 45% of respondents reported using more than 25% of class time in active learning and one year after the Workshop 67% of respondents reported using more than 25% of class time in active learning. In our results, we found that 49% of respondents used more than 25% of class time in active learning in 2008 compared to 81% in 2019. The post-workshop results from Chasteen *et al.* results are in the same ballpark of our 2019 survey results. Of course, we would not expect them to be identical since Chasteen *et al.* report active learning by new faculty which is a different sample that we report here.

These findings are very encouraging. However, there is still room for improvement. Few studies exist that attempt to determine what percent of class time devoted to active learning is ideal. Theobald *et al.* [26] report on a meta-analysis of 41 studies of undergraduate science, technology, engineering, and mathematics (STEM) classrooms comparing exam scores and passing rates of racially under and overrepresented students experiencing an active learning or traditional lecturing class format. They found that high use of active learning decreased achievement gaps, where high use of active learning was defined as using active learning for more than ⅔ of class time. We find that only 36.2% of physics instructors in the 2019 survey report using active learning for 66% or more of class time (compared to 9.1% in 2008). While the large increases in reported time in active learning are encouraging, and almost all faculty report knowing about and using at least some active learning techniques with many using high levels of active learning, the majority (nearly ⅔ of faculty) are still likely not using active learning at sufficiently high levels to reach the best results.

C. Instructors still utilize mostly RBISs that supplement lectures rather than strategies that focus the course on active learning

While the findings reported above show that significant progress has been made in the use of research-based instructional strategies of introductory physics instruction in U.S. higher education, there is still substantial room for improvement. One of the things that we know from the literature is that, while use of any RBIS is better than a traditional lecture class [26–30], the more that a RBIS incorporates student-centered activities over instructor-centered activities, the higher the levels of student learning tend to be [31–33]. Thus, while one of the strengths of Peer Instruction is that it is easily incorporated into a traditional lecture-based physics course, one of the weaknesses is that it may not be as robustly associated with positive learning outcomes as RBISs such as studio-style instruction that require fundamental changes to the course structure.

Data from the 2019 survey for all RBISs asked about is presented in Tables IV and V. In Table IV we rank the 14 RBISs queried based on the percent of respondents who indicated knowledge of the RBIS (i.e., they indicated knowledge regardless of reported use). In Table V we rank the RBISs based on the percent of respondents indicating they are current users of the RBIS. Table V shows that there are four RBISs used by more than 50% of faculty (Peer Instruction, computer simulations and animations, concept inventories, and small-group work). All of these are relatively easy to incorporate into a traditional lecture setting which is likely why they are more frequently uptaken than other RBISs. In contrast, Studio, SCALE-UP, and flipped classroom, the strategies associated with stronger student learning [32], are used by less than ⅓ of faculty.

As discussed previously, while most instructors are using some active learning, they are likely not using it at sufficiently high levels to achieve important outcomes.

TABLE IV. Percent of respondents reporting knowledge of the RBIS in 2019, broken down by institution type. The RBISs are ordered from the strategy with highest level of knowledge to least. Knowledge is defined as respondent reporting being familiar with the strategy, having used it in the past, or are currently using it. The overall sample comprises 22% TYC instructors, 32% BA instructors, and 46% Grad instructors.

Reported knowledge of common RBISs				
RBIS	All institutions	TYC	BA	GRAD
Comp sim, anim	93%	94.5%	94.9%	90.3%
Flipped classroom	91.9	88.2	94.7	91.3
Peer Instruction	89.2	81.1	93	89.9
Small-group work	88.9	84.8	92	88.2
Interactive lecture demos	88.5	85.3	93	86.1
Concept inventories	87.3	76.6	94.2	86.6
Just-in-time teaching	81.4	72.3	86.3	81.7
Think-pair-share	80.9	76.2	86.3	78.3
Studio/SCALE-UP	73.6	66	76.9	74.5
Peer-led team learning	69.9	60.6	73.1	72
Tutorials intro physics	68.8	63.8	75.5	65.1
Concept maps	65.3	67.6	70	59.5
Peer-rev sci writing	57.2	55	62.6	53.2
Ranking or TIPERs	54.3	61.3	57.8	47.1

The reliance on techniques designed to supplement traditional lecture is likely a limiting factor in increasing overall use of active learning. The amount of class time spent in active learning can likely be increased by promoting the use of strategies designed to support a primarily active learning classroom rather than strategies designed to add active learning to a traditional lecture based course.

TABLE V. Percent of respondents reporting current use of the RBIS in 2019, broken down by institution type. The RBISs are ordered from the strategy with highest level of use across all institution types to least. The overall sample is comprised of 22% of TYC instructors, 32% of UG instructors and 46% of Grad instructors.

Reported use of common RBISs				
RBIS	All institutions	TYC	BA	GRAD
Peer Instruction	60.2	50.4	67.2	58.9
Comp sim, anim	56.3	61	59.8	50.5
Concept inventories	52.8	45.2	60	50.2
Small-group work	51.4	54.9	53.7	47.4
Interactive lecture demos	49.5	50.4	53.3	45.4
Think-pair-share	46.7	43	55.5	40.4
Flipped classroom	31.7	28.3	31.6	33.6
Ranking or TIPERs	29.5	37	28.9	26.1
Studio/SCALE-UP	25.7	31.5	26.5	21.8
Just-in-time teaching	25.5	17.6	28.7	26.8
PLTL	25.3	16.1	25.7	29.8
Tutorials intro physics	21.8	22.6	23.3	20.1
Concept maps	15.8	21.8	14.5	13.9
Peer-rev sci writing	6.1	9.7	6.1	4.1

We note that while there are consistent findings in the research literature that more active learning tends to be better than less, the research base does not provide sufficient knowledge about how much active learning (vs lecture) is ideal, or which types of active learning produce better outcomes. As the majority of instructors move toward at least some active learning use, it is essential for change agents to engage in more research to understand better how to guide them in the best use.

D. Biggest leverage point for change agents has shifted from preventing discontinuation to supporting consistent use

As noted earlier, one of the major findings from the 2008 survey is that a large percentage of instructors who started using a RBIS ended up discontinuing use. Specifically, in 2008, 32% of instructors who tried an RBIS ended up discontinuing that RBIS and not using any RBIS. This represented the biggest loss point in the adoption continuum. The list of specific RBISs respondents were asked about are similar but not identical to those from the 2008 survey, and even for those that are the same, the different landscape of RBIS offerings makes it difficult to meaningfully compare use and discontinuation of specific RBISs. However, we can look for other indications of where most instructors currently exist on the adoption continuum.

In the 2019 survey we found that 87% of respondents reported the current use of at least one RBIS, and only 4% of instructors who tried an RBIS reported discontinuing that RBIS and not using any RBIS. Thus, in contrast to 2008, discontinuation is no longer a big problem. Yet, there is still room for improvement.

In the 2019 survey we asked a series of questions about consistent use of RBIS that were not asked on the 2008 survey. Prior to the questions about use of specific RBISs, participants were asked general questions about their use of RBIS using the evidence-based instructional practice adoption scale [34]. Participants were given a general definition of RBIS ("RBIS refers to *research-based instructional strategies* or approaches that have a demonstrated record of success. That is, there is reliable, valid empirical evidence to suggest that when instructors use RBISs, student learning is improved. Some RBISs are active learning techniques, such as just-in-time teaching, process oriented guided inquiry learning, think-pair-share, cooperative learning, and service learning.") and asked to respond "yes" or "no" to the six statements shown in Table VI. Note that the original scale from Landrum *et al.* contained seven items. Our survey did not use the item, "I am curious about how my teaching would change if I used more RBISs."

These questions about consistent use show that, even though, as reported earlier, 87% of respondents indicate

TABLE VI. Responses to questions about knowledge and use of RBIS in general.

	% of respondents answering "Yes"
Prior to this survey, I already knew about RBISs	83%
I have thought about how to implement RBISs in my courses	81%
I've spent time learning about RBISs and I am prepared to use them	72%
I consistently use RBISs in my courses	56%
I consistently use RBISs and I continue to learn about and experiment with new RBISs	53%
I have evidence that my teaching has improved since I started using RBISs	39%

using at least one RBIS, only a bit more than half report consistently using RBISs and continuing to learn and experiment with new RBISs. So while total discontinuation is not currently a problem, the gap between RBIS use and consistent RBIS use is large. Along with previously reported data, this suggests that, although there have been significant improvements in the teaching of introductory physics between 2008 and 2019, there is still room for additional improvement. Previously, we recommended that change agents should focus on helping instructors implement RBISs successfully in order to prevent discontinuation. Now that discontinuation is not a problem, it is important for change agents to shift their focus and emphasize consistent use of RBISs.

IV. LIMITATIONS

All of the data reported in this paper are from faculty self-reported instructional practices. There is surprisingly little research-based evidence about how accurately faculty are able to self report on their instructional practices. Ebert-May and colleagues [35] found that instructors overestimate their use of RBISs. This study asked instructors about their use of six active-learning instructional strategies, such as "cooperative learning" and "guided inquiry-based labs." This is most similar to the part of our study where we ask instructors to report on their use of specific RBISs. Thus, consistent with our prior interview-based study [36] and other survey work [37], the instructors in our study likely overstated their use of named instructional strategies. On the other hand, Smith and colleagues [38] found that instructors did accurately report on time spent lecturing. They compared observations to instructor-self report of percent of class time spent lecturing for 51 college STEM courses and concluded that "faculty members are generally reporting what happens in their classes" (Smith *et al.* [38], p. 632). In another study, Chasteen *et al.* [6] surveyed physics instructors and asked them to self-report about their teaching practice in many different ways. They found that self-reports of time spent in active learning were consistent with other self-reports. Thus, there is some reason to think that instructors are capable of meaningfully reporting on the percentage of class time spent in active learning and, it may also be the case that the parts of our study that rely on instructor self-report of percent time spent lecturing are closer to reality than those that rely on the self-reported use of a specific RBIS.

Another possible concern about the use of self-report of the percent of class time spent lecturing as an important indicator of instructional quality is that there are many different things that an instructor could do in place of lecturing. Some of these are almost certainly better than others. From the survey results we do not have sufficient information to judge the quality of instructional strategies that were implemented in place of lecture. In light of these potential concerns about the use of self-reported data, one strength of the current study design is that the 2008 and 2019 studies both used the same types of questions to gather data about instructional practices. This means that differences in responses between the two surveys are not likely due to biases resulting from the use of self-reported data.

The survey questions about instructors' knowledge and use of named RBIS were developed and analyzed using Rogers' diffusion of innovations model. We note that others have critiqued the model as being overly simplistic and not representing the richness of instructional change. For example, some researchers [6,39,40] have proposed that faculty do not move along the adoption continuum in a linear fashion but rather progress more cyclically, adding and dropping and adding again as they move toward sustained implementation. Strubbe *et al.* [39] suggest that a focus on which teaching techniques instructors use is too narrow and advocate for an "asset-based agentic paradigm" which focuses on the instructor's productive ideas and values over which RBIS they use. We wholeheartedly agree that the diffusion of innovations is overly simplistic and does not fully capture the complexity of real human beings navigating the change process. However, we also feel that Rogers' model and the resulting categorization criteria of knowledge and use provide a meaningful way to think about this complex phenomena.

V. SUMMARY

In this paper we examined results of a national survey of physics instructors to identify their level of knowledge and use of research based instructional strategies and compared it to a similar survey conducted in 2008. We find numerous indications that instructors are utilizing more research-based pedagogies associated with more positive student outcomes. Specifically we find that,

1. Knowledge and use of named strategies has increased. Currently, 98% of instructors report knowing about one or more RBIS (compared to 88%

in 2008). And, 87% of instructors now report using one or more RBIS (compared to 49% in 2008).
2. Fewer Instructors report using primarily lecture-based instruction. In 2008, 66.5% of faculty reported spending 35% or less of class time using active learning. This dropped to 28.2% in 2019.
3. Discontinuation of RBIS is no longer the biggest loss point in the adoption pathway. Discontinuation of a RBIS after trying fell from 32% in 2008 to 4% in 2019.

These findings are very promising and suggest that work by members of the physics community to promote high quality undergraduate instruction are having a positive impact. Our study also uncovered areas where additional work is still needed. Specifically we find that,

4. The highest levels of adoption are associated with the less productive strategies. The most commonly used RBISs are the ones that are the smallest departure from lecture-based courses. While this makes them easy to implement in many situations, RBISs that are more of a departure from a traditional lecture course (such as SCALE-UP or flipped classrooms) are capable of producing stronger positive student outcomes. While use of these more robust active learning techniques has increased over the last decade along with lecture-based ones, their use is still not the norm.
5. The reported time spent lecturing is still too high. While the percent of class time devoted to active learning has increased, it is still likely not yet high enough. The currently limited data suggest that the best student outcomes are associated with classes where at least ⅔ (66%) of class time is spent in active learning. In the 2019 survey, only 36.2% of physics instructors report using active learning for 66% or more of class time.

VI. RECOMMENDATIONS

Our findings suggest several ways the physics education community can continue to improve support for instructors to shift teaching toward improved student outcomes. Suggestions for change agents based on this work include the following:

1. Make the focus of change efforts on supporting instructors to use high quality of active learning implementation. The main leverage point in the adoption continuum is no longer in convincing instructors of the value of active learning nor in getting them to incorporate some RBISs in their teaching. It is now supporting them to adopt higher quality strategies and to implement them consistently. Based on the available evidence [31–33], we suggest that change agents should focus efforts on motivating and supporting instructors to use more RBISs that are not primarily supplements to lecture (i.e., studio or SCALE-UP) and increase the time spent in active learning to be at least ⅔ of class time.
2. Shift research on RBISs from demonstrating that RBISs are better than traditional lecture-based courses to better understanding the strengths and weaknesses of different types of active learning instructional styles. Many earlier studies in PER were designed to show that specific RBISs led to better outcomes than traditional instruction [41]. It is now well established that nearly any form of active learning will produce better student outcomes than traditional lecture-based instruction [27]. There is no need to conduct additional research on this point. What is needed, though, are studies to better understand how to optimize active learning. This includes research on what types of RBIS result in the best learning gains, as well as research on what are the optimal levels of percentage of class time spent in active learning. In addition, we suspect that the answers to these questions will likely depend on the instructional contexts and desired learning goals.

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APPENDIX

Below are the descriptions provided to respondents of the RBISs queried on the survey. Those which were also asked about on the 2018 survey are marked with a *.

1. Concept inventories

Multiple-choice assessments which cannot be answered via calculation, only through conceptual understanding (e.g., Force Concept Inventory, Calculus Concept Inventory, Chemistry Concept Inventory).

2. Concept maps

Students generate diagrams that describe processes, concepts, and the interrelationships between them for a particular content area.

3. Flipped classroom

Primary mode of delivery of content occurs outside of the classroom (i.e., using videos, textbook, activities) and the application of content occurs inside the classroom.

4. Formal small group work*

Use of assigned small groups in which individuals are responsible for their own learning as well as that of others in the group (e.g., collaborative or cooperative learning).

5. Interactive lecture demonstrations*

A prelecture activity wherein students predict the outcome of a demonstration, experience the demonstration, and reflect on the outcome and how it compares to their initial prediction.

6. Just-in-time teaching*

Students complete a preclass assignment which the instructor reviews before class, and adjusts class emphasis and discussion based on students' responses.

7. Peer Instruction*

The instructor poses a question, after which students are given time to reflect and select an answer. The instructor reviews these responses while students discuss their thinking and commit to a (possibly new) answer—the instructor then reviews these to decide whether or not students are ready to move on.

8. Peer-led team learning (PLTL)

Students who have previously taken (and succeeded) in the course act as peer leaders, leading weekly problem-solving sessions related to course material.

9. Peer-reviewed scientific writing

Students submit written assignments including term papers and laboratory reports that are peer reviewed before submitting final versions (e.g., Calibrated Peer Review, MyReviewers).

10. Ranking task exercises in physics and/or TIPERs*

Activities asking students to make comparative judgments about variations on a particular physics situation; tasks Inspired by physics education research.

11. Studio or SCALE-UP*

Students work in small groups on hands-on activities, simulations, interesting questions or problems for the majority of the class period.

12. Teaching with computer simulations and interactive animations*

Interactive computer animations, in which variables of the system or other aspects can be manipulated, are used to supplement classroom instruction (e.g., Phet simulations).

13. Think-pair-share

Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions, followed by whole classroom discussion of students' responses.

14. Tutorials in introductory physics*

Lecture tool where students complete a written activity during or after lecture, often in small groups.

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