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Benefits of a College STEM Faculty Development Initiative: Instructors Report Increased and Sustained Implementation of Research-Based Instructional Strategies

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The Summer Institutes on Scientific Teaching (SI) is a faculty development workshop in which science, technology, engineering, and mathematics (STEM) instructors, particularly from biology, are trained in the Scientific Teaching (ST) pedagogy. While participants have generally reported positive experiences, we aimed to assess how the SI affected participants' teaching practices. Building on a previously developed taxonomy of ST practices, we surveyed SI participants from the 2004–2014 SI classes regarding specific ST practices. Participants' self-reported use and implementation of ST practices increased immediately after SI attendance as well as over a longer time frame, suggesting that implementation persisted and even increased with time. However, instructors reported implementation gains for some practices more than others. The practices with the highest gains were engaging students in their own learning, using learning goals in course design, employing formative assessment, developing overarching course learning goals, representing science as a process, and facilitating group discussion activities. We propose that the ST practices showing the greatest gains may serve as beneficial focal points for professional development programs, while practices with smaller gains may require modified dissemination approaches or support structures.

INTRODUCTION

Over the past few decades, several national efforts have called for changes in undergraduate science, technology, engineering, and mathematics (STEM) education (1–6). In 2003, a report by the National Research Council offered a series of pedagogical recommendations to transform undergraduate biology education to more closely reflect the nature of science (3). In response to this call, the Summer Institutes on Scientific Teaching (SI; formerly titled the National Academies Summer Institutes on Undergraduate Education in Biology) was developed to provide training for undergraduate instructors, particularly within biology. SI participants complete an intensive week-long training workshop on the Scientific Teaching (ST) pedagogy (7–9), which includes many of the best practices recommended in national reports. During the SI, participants engage in sessions on inclusive teaching, active learning, assessment, how people learn, institutional transformation, and putting ST into practice. Participants also work in teams to develop a "teachable tidbit" incorporating research-based instructional strategies, and the tidbit then serves as a starting point to help SI alumni integrate ST practices in their own courses. The SI thus aims to transform undergraduate science courses from passive, lecture-based approaches to more active, evidence-based approaches that engage all students in their own learning. Given the longevity of the

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SI, the geographic spread of its six regional institutes, and the numerous instructors trained at the SI to date, this program has had the capacity to make a broad impact on undergraduate education.

While early investigations reported promising impacts of SI participation, additional questions remained regarding the degree to which SI participants adopt and continue using ST practices in their courses (10, 11). To investigate the impact of the SI on prior participants, an online survey was created and emailed to program alumni to gauge implementation of practices defined in the ST taxonomy (9, 12). We used the data from this survey to test the hypothesis that the SI enabled participants to incorporate ST practices in their courses after SI participation. We explored how the reported use and implementation levels of ST practices changed immediately after the SI and in subsequent semesters as well as whether changes varied across different SI cohorts. By conducting these investigations, we sought to better understand how participants perceived the SI to have affected their teaching as well as identify practices that were more or less amenable to implementation.

METHODS

Census administration and data processing

An electronic link to the Summer Institutes Census Survey (hereafter referred to as the census) was disseminated via e-mail to all 1,179 SI alumni in October 2014 by the Yale Center for Scientific Teaching. The link remained open for 2 months, and 750 alumni accessed the survey. Demographic information and other survey administration details are available (12). Census responses were initially filtered to remove participants who did not meet inclusion criteria because they were retired, were not instructors, did not complete more than half of the census questions, did not consent to participate in the study, or had no variance in their responses. This left $n = 602$ responses in the final data set, which represented 51% of all participants contacted.

The census contained of a variety of questions related to the use and implementation of ST practices, personal views about teaching and learning, and individual and professional demographics. Here, we focus on the questions related to ST practices. Participants were asked initial questions about their experience with 18 different teaching practices (Appendix 1) on an adoption process scale ranging from personal exposure to use in their courses. Respondents who indicated that they did not use a practice were considered to have "never used" that practice at any time. Respondents who reported using a particular teaching practice were directed to additional questions about the frequency at which they implemented this practice at three time points: "before attending the SI" (pre-SI), "my first semester after the SI" (post-SI), and "my teaching now" (current), referring to Fall 2014, when the census was administered. These respondents were asked to indicate their implementation level for each ST practice at each time point by selecting one of the following choices: (a) "not aware of this method," (b) "aware of this method but never used it," (c) "use/used this method once or twice," (d) "use/used this method some classes," (e) "use/used this method most classes," and (f) "use/used this method every class." Participants from the 2014 SI class were excluded from some analyses because their post-SI and current time points referred to the same semester, leaving $n = 448$ in those cases.

Statistical analyses

We used the ST taxonomy (9) to group individual practices into five categories: Student Participation, Course Alignment, Science Practices, Cognitive Processes, and Inclusivity (Appendix 1). We analyzed reported practices in each ST category using several different metrics.

To calculate practice use (i.e., whether practices were implemented at all), we first converted census responses to 0 if no implementation was indicated (census answers choices a and b) and 1 if the respondent indicated implementation of the practice at least once (answers c to f). We then calculated the proportion of practices used within each category for each respondent and determined the mean proportion of practices used across respondents. We performed repeated-measures analyses of variance (ANOVAs) for each category with post hoc Bonferroni-corrected pairwise comparisons to determine if the proportion of practices used differed between the three time points.

To estimate implementation levels (i.e., how often practices were implemented), we first converted census responses for the individual practices into numerical values. We then averaged these values across all practices in each category to get an individual respondent's implementation level. Implementation levels were averaged across all respondents, and we performed repeated-measures ANOVAs for each category with post hoc Bonferroni-corrected pairwise comparisons to determine whether average implementation levels differed between time points. To characterize the distribution of implementation levels, we calculated the percentage of respondents selecting each option for each item, then averaged these percentages across each category.

We next investigated how commonly implementation gains (i.e., an increase in implementation levels) occurred during the initial (pre-SI to post-SI) and subsequent (post-SI to current) time periods by determining whether a gain occurred during these periods for each practice. We then calculated the percentage of respondents with gains for each item and averaged these percentages across each category.

We further analyzed implementation changes (i.e., amount of change in implementation levels) during these time periods for different SI cohorts. Participants were classified into "early" (2004–2007; $n = 49$), "middle" (2008–2010; $n = 62$), and "recent" (2011–2013; $n = 337$) cohorts. These designations were established based on key events that could have impacted participant experiences and recruitment (i.e., formalization of the SI curriculum in 2008 and expansion from one location to six regional institutes in 2011), and the unequal numbers in these groups stem from SI growth. We calculated the category implementation changes for each respondent and then averaged the changes for each cohort. We tested for differences in implementation changes across cohorts using ANOVAs for the initial and subsequent periods with post hoc pairwise Tukey tests.

All analyses were completed using SPSS. This work was classified as exempt from IRB review at Yale (#1411014955) and at UNL (#15016).

RESULTS

Reported use and implementation levels of ST practices increased after the SI and in subsequent semesters

For all five ST categories, the proportion of practices used increased from pre-SI to post-SI ($F = 116.4–269.4$, $p < 0.0001$) (Fig. 1A; see also Appendix 2A), and some categories were more heavily used than others. At both time points, participants reported using more practices associated with Student Participation, Course Alignment, and Science Practices than practices associated with Cognitive Processes and Inclusivity (Fig. 1A). The proportion of practices used in each category increased modestly from post-SI to current (Fig. 1A), and those increases were significantly different ($p < 0.0001–0.034$; Appendix 2A) between time points for all categories except Student Participation ($p = 0.088$; Appendix 2A). Thus, SI participants reported adopting teaching practices in each ST category immediately after the SI and maintaining the use of those practices over time.

We also investigated differences in the reported implementation levels of each ST category. Reported implementation of each ST category significantly differed across time points ($F = 186.8–462.4$, $p < 0.001$), and Bonferroni-corrected post hoc pairwise comparisons showed significant increases for each category between all time points ($p < 0.001$) (Fig. 1B, Appendix 2B). These results indicated that SI participants reported increasing the frequency at which they implement ST practices both after SI participation and in subsequent semesters.

Participants reported increased awareness and implementation levels for ST practices over time

To further visualize changes in ST practices, we plotted the distribution of reported implementation levels for the pre-SI and current time points. Many respondents reported that prior to the SI they were either unaware of, did not use, or infrequently used most of the ST practices (Fig. 2A). However, four of the five ST categories showed more regular implementation levels (some, most, or every class) at the current time point by at least half of the respondents, including a sizeable percentage of respondents reporting implementation in most or every class (Fig. 2B). The fifth category, Inclusivity, also showed increases in implementation levels, but fewer than half of the respondents ever used inclusive practices. Implementation level distributions for individual practices can be found in Appendix 3.

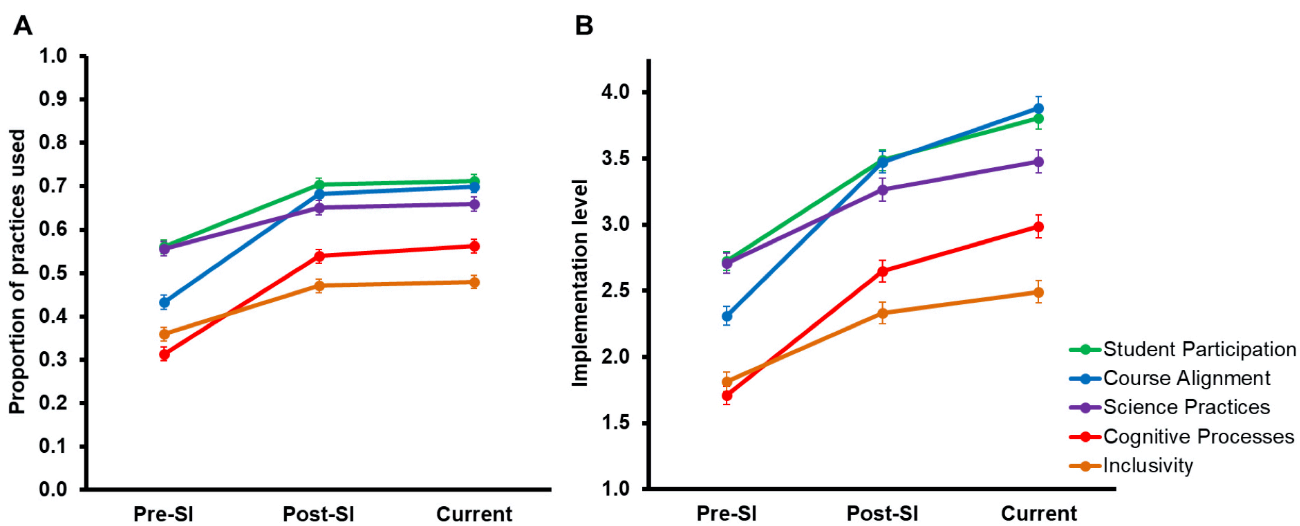

FIGURE 1. Reported ST practice use and implementation levels for each category at different time points. Dots represent the mean proportion of practices used (A) or mean implementation levels, which reflect the frequency of practice implementation (B). Standard errors of the means (SEM) are shown. All three time points were reported on the 2014 census. Data come from respondents from SI years 2004–2013 ($n = 448$ respondents).

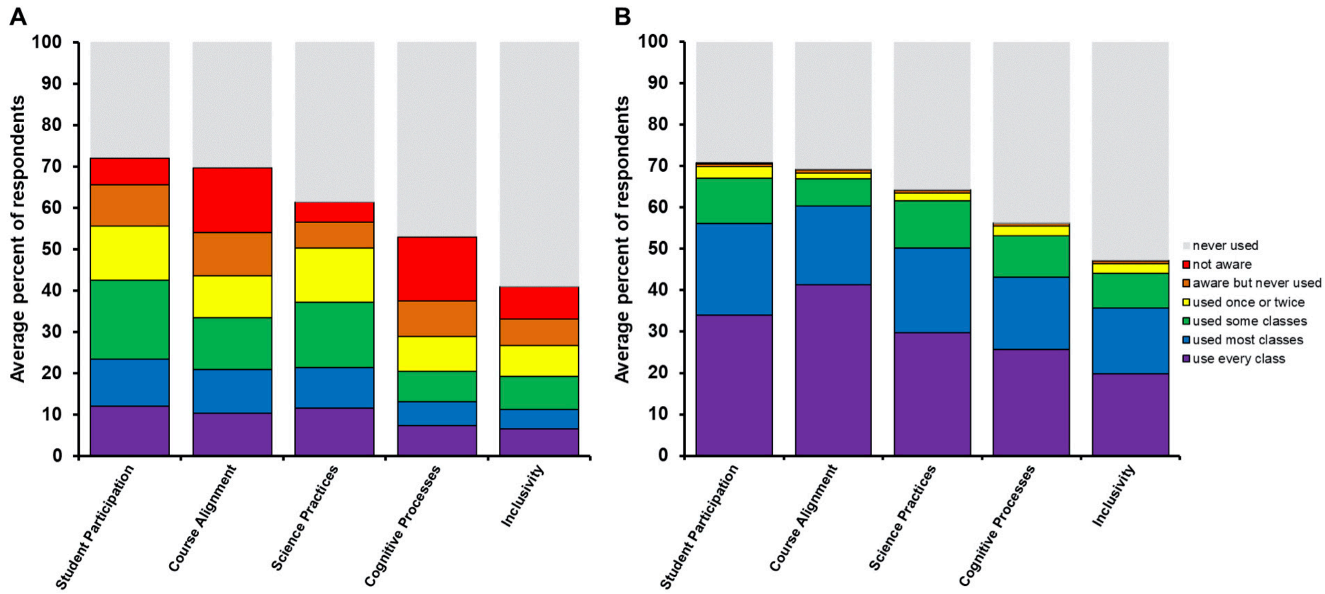

FIGURE 2. Distribution of reported implementation levels before attending the SI (A) and at the time of the SI census (B). Stacked bars represent average percentages of respondents who selected the given frequency in each ST category. The gray portion of each bar represents respondents who indicated that they never used the practice on the initial question (*n* = 602 respondents).

Individual participants reported gains in implementation levels after the SI and in subsequent semesters

We investigated how individuals changed implementation frequencies after SI attendance by calculating the average percentages of respondents who showed gains in their reported implementation levels across different time frames. Implementation gains could occur during only the initial period, during both initial and subsequent periods, or during only the subsequent period. The average percentage of respondents who indicated a gain in implementation levels was larger for some categories than others, with a range of 27% to 54% of respondents reporting gains for each category (Fig. 3) and 17% to 63% of respondents reporting gains for individual practices (Appendix 4). In both the initial and subsequent periods, Course Alignment had the largest and Inclusivity had the smallest percentages of respondents reporting gains (Fig. 3). In terms of individual practices, engaging students in their own learning, using learning goals in course design, employing formative assessment, developing overarching course learning goals, representing science as a process, and facilitating group discussion activities most commonly showed gains. Conversely, reducing implicit bias, representing diversity, connecting science to society, fostering class-wide discussion, using inclusive teaching, and stimulating metacognition had the lowest gains.

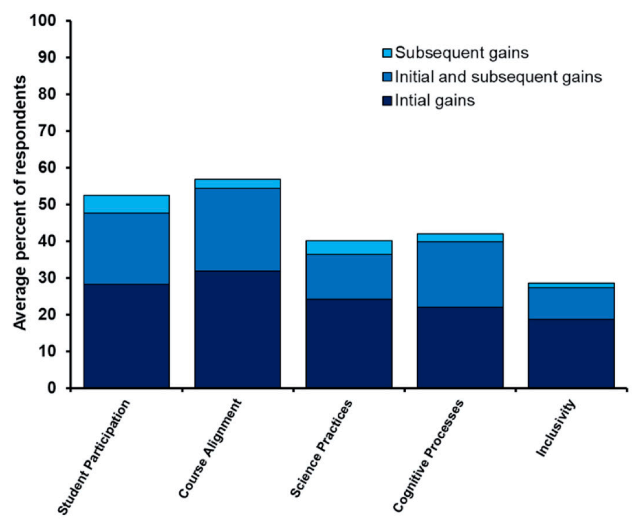

FIGURE 3. Reported ST implementation gains. Stacked bars represent the average percentages of respondents who indicated an implementation gain for each ST category during the given time frames. The dark blue segments represent gains only in the initial period (pre-SI to post-SI), the medium blue segments indicate gains in both periods, and the light blue segments represent gains only in the subsequent period (post-SI to current). For example, under Student Participation, 28% reported only initial gains, 19% reported initial and subsequent gains, and 5% reported only subsequent gains. Data come from respondents from SI years 2004–2013 (*n* = 448 respondents).

Reported ST practice implementation levels increased with time after SI participation

Finally, we analyzed changes in reported implementation levels between SI cohorts (early, middle, recent). We first examined the implementation changes occurring during the initial time frame to determine if the cohorts had different experiences at the SI. There were no reported differences among cohorts, except for lower initial implementation changes for the recent cohort compared with the other SI cohorts for the Course Alignment category (ANOVA: $F = 6.69$, $p = 0.001$; Tukey test: $p = 0.009$ with early cohort, $p = 0.029$ with middle cohort) (Appendices 5 and 6). If participants continued to increase the implementation frequencies of ST practices over time, earlier cohorts would be expected to have larger subsequent changes than more recent cohorts because more time had passed since their SI attendance. While reports of subsequent changes were generally lower than initial changes for all cohorts, reported implementation changes showed increases with time across cohorts ($F = 12.08$–27.05, $p < 0.001$) (Fig. 4), and pairwise comparisons showed significant differences for all but three comparisons between cohorts (Appendix 7). These results suggest that, compared with the more recent cohorts, earlier SI participants generally reported higher implementation changes during the subsequent time period.

DISCUSSION

As one of the largest and longest-running undergraduate faculty development programs in the country, the SI has had a unique vantage from which to catalyze change in undergraduate STEM education. While early reports and program evaluation provided promising evidence that the SI influences participants' teaching practices (10, 11), the SI census survey was deployed to gauge participants' perceptions of whether and how their teaching practices might have changed over time (12).

Respondents increased their use and implementation of ST practices directly after SI participation

In general, respondents indicated that the SI had a substantial impact on their courses. Respondents reported that prior to SI participation, most of the ST practices were either not used or implemented infrequently (once, twice, or some classes) (Fig. 2A). In comparison, respondents reported using more ST practices the first semester after the SI (Fig. 1A), and likewise, respondents indicated increases in their implementation levels (Fig. 1B). This result has practical implications for instructors or departments who aim to implement changes in teaching methods, because it suggests that SI participation can lead to immediate changes and

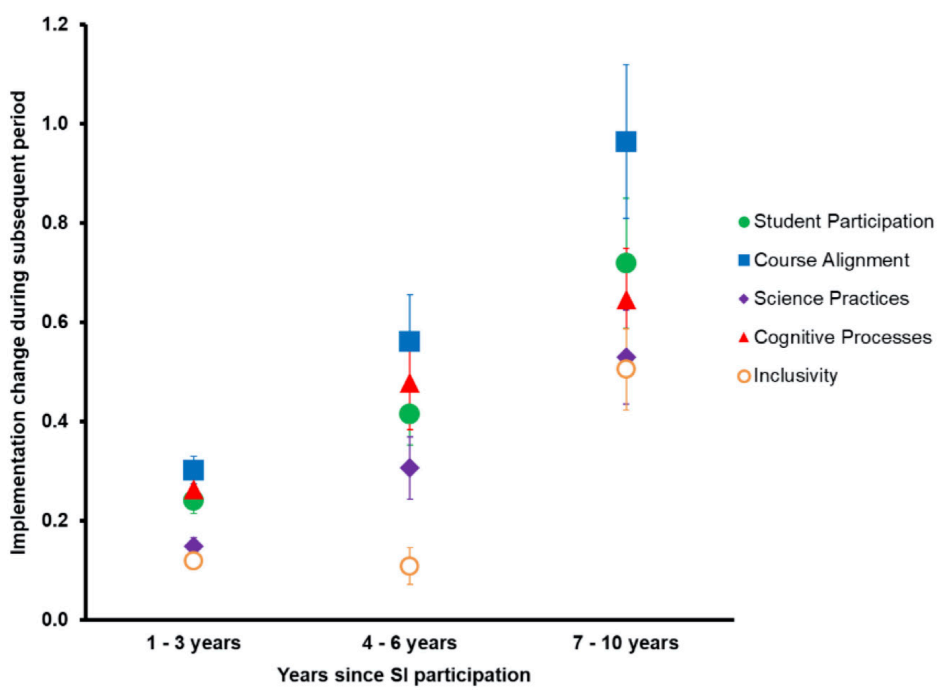

FIGURE 4. Reported subsequent changes in ST implementation as a function of time since SI participation. Symbols represent the reported implementation changes for each SI cohort during the subsequent period (i.e., post-SI to current) (means ± SEM). Cohorts consisted of respondents from 1–3 years ago (recent cohort, SI years 2011–2013, $n = 337$), 4–6 years ago (middle cohort, SI years 2008–2010, $n = 62$), and 7–10 years ago (early cohort, SI years 2004–2007, $n = 49$).

influence the student experience as early as one semester after attending.

Increased ST implementation persisted over time

In addition to immediate changes, we also wished to understand how implementation changed over the subsequent semesters after SI participation. Instructors who indicated ST practice adoption post-SI maintained their use of the practices, and a small proportion of additional respondents reported adopting ST practices for the first time during the subsequent time period (Fig. 1A). This smaller increase in new users during the subsequent time period suggests that in the absence of the SI, these instructors generally did not adopt new practices. However, the overall reported implementation levels increased during the subsequent time period, suggesting that instructors continued to increase the frequency at which they implemented ST in their courses long after SI participation (Fig. 1B). While these implementation increases were of a smaller magnitude than those indicated during the initial time frame, we recognized the potential for these changes to accumulate over time. Indeed, we detected a trend in which earlier cohorts reported higher subsequent implementation changes than more recent cohorts (Fig. 4). These differences could have stemmed from a variety of factors, including instructors becoming more comfortable with ST practices over time, earlier participants returning to serve as SI leaders, or differences in the incoming composition of each cohort (e.g., as the program expanded, graduate students/postdoctoral researchers and instructors from non-biology disciplines constituted a larger proportion of SI participants). Regardless of the underlying cause, these results suggest that instructors continued to use ST practices over time and that the frequency of these practices increased, culminating with implementation of many practices in some, most, or all class sessions at the time of census administration (Fig. 2B).

ST practices differed in their reported implementation gains

While the SI had a positive effect on reported implementation of all practices, some individual practices showed more prominent gains than others. The practices with the greatest gains were engaging students in their own learning, using learning goals in course design, employing formative assessment, developing overarching course learning goals, representing science as a process, and facilitating group discussion activities (Appendix 4). These six practices represent core components of the ST framework and SI curriculum, and there are several possible reasons why these practices may have showed higher gains than others. For example, SI participants can start developing learning goals directly after attending the SI, and the establishment of learning goals may serve as a "gatekeeper" that affects the implementation of other ST practices. Once the learning goals for a course have been developed, instructors can then create formative assessments and group activities that engage students in their own learning. Furthermore, some of these practices may be easier to implement and feel less threatening to established course norms (13, 14). For example, engaging students in their own learning and group discussion can be readily achieved through think-pair-share activities or peer instruction strategies, which require comparatively less preparation or class time (15, 16). Conversely, a practice like engaging students in class-wide discussions may require more class time and depend on an instructor's ability to cultivate dialogue and the students' enthusiasm for participation.

In addition to fostering class-wide discussion, the practices of reducing implicit bias, representing diversity, connecting science to society, using inclusive teaching, and stimulating metacognition had the smallest gains (Appendix 4). With the exception of connecting science to society, these practices also had the lowest implementation levels, with fewer than 50% of respondents reporting use at any point (Appendix 3). The reports of low frequencies may have been due, in part, to instructors' views that these teaching practices are most effective when incorporated only occasionally. For example, an instructor might incorporate monthly surveys to help students reflect metacognitively on their study process, rather than incorporating such an activity on a more frequent basis. The low rates at which participants reported incorporating certain practices may also stem from personal views about teaching or other external constraints. Previous research using the same census data found that instructors with multicultural ideologies more readily adopted inclusive teaching practices than individuals with colorblind ideologies, suggesting that people who recognize differences among students are more likely to take proactive steps to embrace these differences in their teaching (12). Instructors may also feel conflict between expectations to cover large amounts of content and a desire to incorporate "additional" materials or activities (17).

Despite their lower reported gains, encouraging metacognition and teaching inclusively can have positive effects on students and have the potential for broad-scale impacts. Metacognitive activities can improve student learning and help students become self-regulated learners (18–20). Inclusive teaching strategies, such as providing course examples to which students can personally relate or highlighting professional role models who possess personal characteristics similar to students from underrepresented groups, can reduce stereotype threat and feelings of alienation, increase science identity, and cultivate a sense of belonging (5, 8, 21, 22). These benefits to students may, in turn, lead to greater retention of underrepresented groups in STEM majors and workforce diversification (23).

Other considerations

While this study describes promising outcomes, we recognize certain limitations affecting the interpretation and generalizability of the survey results. The census was a self-report instrument that asked respondents to provide a retrospective estimation of their own implementation levels at three time points. The use of self-reports for this purpose has been questioned because instructors may overreport practices to provide more favorable views of a professional development program (24). However, given the significantly greater resources needed for other approaches (e.g., classroom observations, student surveys, artifact analysis), instructor self-reporting has been a common method for gauging teaching practices. This method has been used to estimate the use of specific practices, conduct detailed investigations on the fidelity of implementation of research-based instructional strategies, and determine the impact of professional development programs (25–33). Importantly, we recently conducted a systematic comparison of how instructors, students, and external observers compare in how they report ST practices using the Measurement Instrument for Scientific Teaching (MIST), and we found reasonable congruence between these different perspectives, particularly for practices associated with active learning (34, 35). While we have evidence that instructor reports can agree with other perspectives for many ST practices, the data are most appropriately interpreted as participants' perceived changes in teaching practices over time.

Additionally, SI participants represented a pool of instructors who were motivated to apply for and attend a week-long intensive teaching workshop, and the 51% SI census participation rate resulted in a further selected subset of all SI attendees. This rate exceeds other large-scale faculty teaching practice surveys, which have seen response rates of 50% (25), 39% (27), 36% (32), 28% (31), and several less than 20% (28–30, 33). Attendees who had poor SI experiences or encountered student resistance or structural barriers at their home institutions may have been less inclined to respond. This selection effect could explain the generally positive patterns and why very few instructors reported abandoning new teaching practices after initial implementation, whereas other studies have reported that faculty may stop using research-based instructional strategies (25). Thus, the results should not be considered generalizable to the broader undergraduate STEM instructor population or necessarily representative of the experiences of all SI participants. Nevertheless, the results presented here indicate the potential impact that census respondents have had on STEM education. Finally, although the census gathered information about what practices were implemented and at what frequencies, we cannot definitively attribute changes to SI participation. Given the time span covered by the survey, a number of other factors could have influenced ST implementation levels. For example, participants may have attended other professional development programs or taken on new courses, which could have contributed to changes in their teaching practices.

CONCLUSION

The Summer Institute Census Survey results presented here support our hypothesis by showing that respondents perceived the SI to have had an immediate and sustained impact on their teaching practices. While we acknowledging the potential biases and selection effects inherent in the survey methodology, the data provide evidence that many instructors view the SI as a formative moment in their teaching trajectories, facilitating the use and implementation of ST practices. It is unlikely that participants would have been able to adopt the full suite of ST practices, and some practices were reported to be implemented more readily than others after SI participation. Future research is needed to investigate the personal and contextual characteristics that facilitate implementation of certain techniques as well as the specific barriers that limit these practices. Furthermore, the census identified several practices for which respondents reported low use and implementation. This information can be leveraged by the SI and other professional development programs to consider how curricula or approaches might be adjusted to improve instruction.

SUPPLEMENTAL MATERIALS

Appendix 1: Census teaching practice groupings
Appendix 2: Repeated-measures ANOVA results
Appendix 3: ST practice implementation levels at pre-SI and current time points
Appendix 4: ST practice implementation gains
Appendix 5: Initial changes in ST implementation among SI cohorts
Appendix 6: ANOVA, initial implementation changes among SI cohorts
Appendix 7: ANOVA, subsequent implementation changes among SI cohorts

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