BAMS Article

Involvement in and Perception of Atmospheric Science Education Research

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ABSTRACT: Increasing participation in education research and encouraging the use of evidence-based practices in the classroom has been identified as a Grand Challenge in the Geosciences. As a first step in addressing this Grand Challenge, a survey was developed and disseminated to a broad range of atmospheric science professionals to collect data about 1) the number of community members involved in atmospheric science education research (ASER); 2) whether ASER is valued within the community, and if so, to what extent; 3) potential barriers to involvement in ASER; and 4) the resources necessary to encourage involvement in ASER. Survey results revealed that while many in the atmospheric science community highly value education research, barriers to greater involvement include a perceived lack of value and a lack of visibility of ASER. Recommendations are made for addressing these barriers.

KEYWORDS: Social Science; Education; Societal impacts

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The scholarship of teaching and learning (SoTL) focuses on improving education through reflective teaching and a systematic evaluation of student learning. Findings are generally shared publicly at conferences, workshops, or in newsletters [National Research Council (NRC); NRC 2012; Kern et al. 2015]. Discipline-based education research (DBER), rooted in cognitive science, examines teaching and learning in a discipline and seeks to understand how people build foundational knowledge and apply concepts within a discipline. DBER can be conducted in a formal classroom; it might also be investigations into informal learning that occurs in museums or during outreach activities. Research on continuing education courses and survey research such as this are also considered DBER. DBER is conducted within numerous scientific disciplines (e.g., physics and chemistry, biology, engineering, mathematics, and astronomy), and findings can be generalized to improve teaching and learning in the field and are published in peer-reviewed journals (NRC 2012). The field of geoscience education research (GER), formalized in the 2000s, intentionally includes SoTL because SoTL can provide DBER questions, and DBER theories and findings can be used to improve teaching and learning through SoTL (Manduca et al. 2004; NRC 2012; McNeal and Petcovic 2017; Shipley et al. 2017).

The National Research Council (NRC 2012) has recognized DBER as vital to the advancement of undergraduate science education, and Manduca et al. (2004) emphasized the need for a community of scholars to address challenges and promote improvement in teaching and learning in the field of geosciences. The geosciences include the atmospheric sciences; however, despite growth of the GER community and efforts for greater inclusiveness by the geoscience community, the atmospheric science community has yet to broadly encourage this type of scholarship (Charlevoix 2008; NRC 2012). As a result, only a small number of atmospheric scientists are actively engaged in education research and literature assessing and promoting pedagogy in the discipline has been sparse relative to other geoscience disciplines (Wilson 2016).

Cervato et al. (2018) classified the lack of participation in education research by the atmospheric science community as a Grand Challenge in GER. In an effort to broaden participation in atmospheric science education research (ASER) and encourage the use of evidence-based practices in atmospheric science, the development of a survey to quantify the size of the ASER community and identify the resources available for ASER was proposed (Cervato et al. 2018). The goal of the current study is to understand why the atmospheric sciences lag behind other disciplines in the adoption of DBER and SoTL. Through a survey to a broad range of atmospheric science professionals we investigate the following:

1) the number of community members involved in ASER;
2) whether ASER is valued within the community, and if so, to what extent;
3) potential barriers to involvement in ASER; and
4) the resources that will provide pathways to increased involvement in ASER.

For the purpose of the survey and this paper, "ASER" refers to both SoTL and DBER activities within the atmospheric sciences. Survey results were analyzed to shed light on the size of the ASER community and to highlight the value of ASER to the broader community. Since SoTL is generally characterized by classroom-level studies aimed at improving one's own teaching, and DBER is often generalizable beyond a single classroom, perceptions of the value of these two types of work will vary considerably. Barriers to conducting ASER are identified, and recommendations are made for growing and supporting the ASER community.

Survey development and distribution

The Involvement in and Perception of Atmospheric Science Education Research (IPASER) survey questions were based on participant discussions during the American Meteorological Society (AMS) 2018 short course: ASER: A Beginner's Guide, as well as the Carnegie Academy for the Scholarship of Teaching and Learning (CASTL) and Faculty Survey on Teaching, Learning and Assessment (FSTLA) surveys (Dey and Hurtado 2000; CASTL Program 2004). The IPASER survey was pilot tested using an independent eight-member review panel (survey available in supplementary material; https://doi.org/10.1175/BAMS-D-19-0230.2). The panel included 1 atmospheric science program director, six faculty of various ranks (including two geoscience education researchers with experience in survey development), and a graduate student. Given the anticipated low response rate from industry professionals, the authors did not request that they review the survey, which calls into question the validity of responses from that group as it cannot be guaranteed that the survey questions were interpreted as intended. However, the low response rate from this group limits the validity concern. The pilot study included an anonymous feedback process during which respondents could comment on each question, if desired. The feedback process led to minor revisions of the survey.

The final version of the survey consisted of 11 demographics questions and 4 questions regarding survey respondents' interest and participation in ASER activities, and their opinion on the value of ASER to the community. Survey respondents who self-identified as either a formal educator (K–12, college, etc.) or an informal educator (after-school programs, community-based organizations, museum educators, etc.) are referred to as "instructor participants." The instructor subgroup was presented with up to 27 additional questions about teaching and learning resources available to them, and recognition received for research related to teaching and learning (see sections 2 and 3 of IPASER survey). Participants were able to skip questions; as a result, the number of respondents varies for each question.

The IPASER survey was distributed online via Qualtrics. While online surveys are a predominant method of survey distribution, response rates are significantly lower than postal surveys. This may be a result of survey fatigue due to the overabundance of online surveys (Porter and Whitcomb, 2005; Saleh and Bista 2017). Several strategies were implemented to ensure the highest possible response rate for the IPASER survey, including the pilot test, assurance of privacy and confidentiality, and strategic timing of initial and reminder emails (Fan and Yan 2010; Saleh and Bista 2017).

Survey distribution began in late November 2018 and closed in early April 2019. The survey was shared within the AMS Community Open Forum, monthly newsletters (e.g., National Weather Association), email listservs (e.g., University Corporation for Atmospheric Research, AMS Boards and Committees), and various social media outlets (e.g., Facebook, Twitter). While member counts from the distribution outlets suggest the survey was distributed to as many as 20,811 respondents, there is likely significant membership overlap between the listservs, social media outlets, and online communities. Hence, the number of participants was calculated using the number of active atmospheric science community members (based on the AMS Community Open Forum), which implies 10,600 respondents were contacted. A total of 338 responses were received. We removed records for those who declined to participate (i.e., participant did not consent), and for participants who consented but did not answer the survey questions, leaving us with a total of 223 respondents. This implies a survey response rate of ~2.05%.

Given the small response rate and the descriptive nature of this study, we are limited in what conclusions can be drawn regarding the survey responses. Additional limitations include the representativeness of the sample (further addressed in the "Demographics" section), and the sampling method (i.e., voluntary response sampling). Despite these limitations, the survey data can be used to describe the current state of ASER as seen by respondents, and the findings can stimulate discussion of the next steps to improving atmospheric science education through research.

Demographics

Approximately 94% of the respondents indicated that they were AMS members. A demographic study of AMS members found that 27% of the 3,970 respondents in 2005 were employed by a university or college, with 14% holding a position as an educator (Murillo et al. 2008, their Tables 6 and 7, hereafter referred to as the AMS study). Table 1 shows that the majority of respondents for this survey held positions within academia, with the overwhelming majority identifying as instructors (64%). The AMS study found that 31% of their survey respondents held research scientist positions, 14% were broadcast meteorologists, and 9% were operational meteorologists (i.e., nonbroadcast). In this study, the remaining 13% of participants were employed as operational meteorologists (just over 3%), program directors (1.26%), consultants, computer scientists, or high school teachers, or held technical positions (latter four groups accounting for less than 1% each; Q4.6, N = 159). Notable drawbacks are validity concerns with the responses from industry professionals, that this study did not sample any broadcast meteorologists, and that it was biased toward females in academia. Given that people are more likely to participate in a study when the topic is related to their interests, this is not surprising for an education-research-focused survey (Saleh and Bista 2017).

Nearly 41% of the respondents identified as female (Q4.1, N = 186). MacPhee and Canetto (2015) examined 34, or approximately 70% of the total number of atmospheric science doctoral programs and found there were 813 tenured and tenure-track faculty employed in atmospheric science in 2009, only 17% of which were female. This suggests that women were oversampled in this study [National Weather Association (NWA); NWA 2016]. For this survey, there were 69 participants that identified as a tenure-track professor at a doctoral institution, indicating that the current study represents nearly 8.5% of the total tenured and tenure-track faculty in atmospheric science. Of the 153 respondents who indicated their tenure status (Q4.9), just over half (52.3%) identified as tenured or tenure track, with females making up 30% of this group. The number of males and females in non-tenure-track jobs was nearly equal (47.7%).

The ages of the respondents for this survey ranged from 18 to 64+ (Q4.3), with approximately 33% of the respondents being over the age of 55 (Table 1). These results are in line with the AMS study which showed that 33% of the AMS community was over the age of 50 in 2005. Approximately 46% of the respondents fell in the 35–54 age range, which generally agrees with the AMS study (see their Fig. 1). The number of respondents from this study who were under 34 (20%) is slightly lower than the AMS study (approximately 30%; their Fig. 1 and Table 9).

Roughly 11% of the respondents self-identified as one or more of the following: American Indian or Alaska Native, Black or African American, East Asian, Hispanic, Latino or Spanish origin, Native Hawaiian or other Pacific Islander, South Asian (Q4.4). This is

Table 1. Demographics data for the IPASER survey.

Category	Percentage
Gender	
Male	57
Female	41
Age	
18–24	3
25–34	17
35–44	28
45–54	18
55–64	17
>64	16
Employment	
Educator	64
Graduate student	4
Postdoc	4
Research scientist	13
Administration	2
Other	13

similar to the 13.1% that self-identified as minorities in the AMS study, indicating that these results are fairly representative of the variety of ethnic backgrounds that make up the atmospheric science community.

Interest in and motivation for education research

The first several questions (Q1.1–Q1.4) were asked of all participants and therefore have the highest response rate of all the survey questions (*N* = 219–222). All participants were asked to classify research that investigates teaching and learning in the field of atmospheric science as "very important," "moderately important," "somewhat important," or "not important." An "I do not know" option was also provided (Q1.2). Nearly 85% of participants classified ASER as moderately to very important (Fig. 1; *N* = 222). In fact, the percentage of participants noting ASER as moderately to very important ranged from 72% to 100%, indicating that ASER is valued by participants across all demographic categories (age, biological sex, race/ethnicity, current position, and tenure status). Participant comments shed light on why they feel ASER is important (Q1.5). Several participants noted that the atmospheric science community lags many other science disciplines in terms of DBER, while others indicated that ASER is crucial to successfully educating future atmospheric scientists as well as the general public.

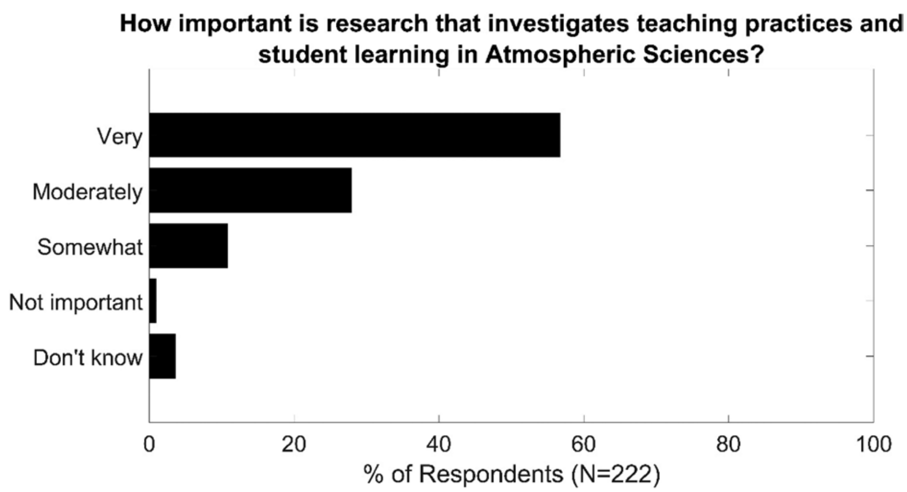

Fig. 1. Responses to Q1.2: "How important is research that investigates teaching practices and student learning in Atmospheric Sciences?"

All participants were also asked to indicate their level of interest in various ASER-related activities such as conducting ASER, presenting ASER, helping establish an ASER community, and using ASER-based materials (Q1.1). Results show that 60.6% (53.4%) of survey participants are moderately to very interested in exploring (developing) questions about student learning, attending a talk/session devoted to education research at a discipline-based conference (59.5%), and 57.5% indicated moderate to high interest in helping establish an education research community in atmospheric science (*N* = 219–221). Other disciplines (e.g., biology, geosciences) have successfully established education research communities by bringing awareness of education research (ER) to the larger community through training, professional development, and presentations, which foster collaborations and encourage participation in ER (NRC 2012). Roughly 44.5% expressed a strong desire to find collaborators with whom to pursue their education research interests, and only 31.9% of the respondents indicated a moderate to high level of interest in presenting education research at a discipline-based conference. Figure 2 highlights the findings of Q1.2; the majority of respondents see the value and benefits of ASER to the community (i.e., 67.7% express moderate to strong interest in using a website to share/find resources for research-based teaching in the atmospheric sciences); however, fewer are personally interested in formal ASER engagement.

Further analysis by demographic categories produced a notable difference in the responses between research scientists and the remaining positions. While 72% of research scientists (*N* = 25) rated ASER as moderately to very important, they were least interested in engaging in ASER activities. For example, while 60% of research scientists indicated a moderate to high interest in exploring questions about student learning, only 24% indicated moderate to high interest in presenting ASER. Perhaps research scientists do not find it feasible to switch their current research focus to ASER activities, but they do see the value in ASER and have questions about student learning, which implies that research scientists would be potential partners for future ASER projects.

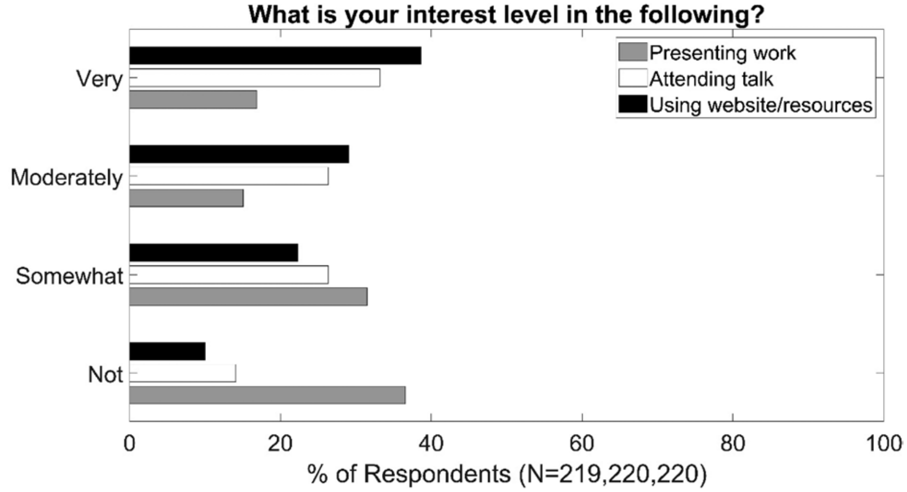

Fig. 2. Survey responses to Q1.1: "What is your level of interest in each of the following?" Responses for "Using a website for resources related to teaching and learning" (black), "Attending an ASER talk" (white), and "Presenting ASER work" (gray; Q1.1).

Perceptions of existing merit structures

It should be noted that the weight that ASER carries toward tenure and promotion would depend strongly on the rigor of the work done and the expectations of one's position. However, instructor's views of ASER work in the context of tenure (Q2.2) and promotion (Q2.4) are not aligned with their perceptions of their institution's views. The majority of instructor participants responded that ASER should carry moderate to significant weight toward promotion (81.6%, $N = 158$) and tenure (80.8%, $N = 156$). However, participants anticipated that their institutions would assign ASER-related conference presentations (Q2.7, $N = 160$) and peer-reviewed journal articles (Q2.8, $N = 159$) less weight than non-education-related research activities (38.8% and 34%, respectively). Specifically, 42.3% (24.1%) of instructor participants anticipated that ASER conference presentations (peer-reviewed ASER journal articles) would not be classified as research endeavors by their department. Survey results show that instructor participants' personal views differ significantly from how they perceive their institutions view education research. Additionally, when asked whether ASER is valued within the broader atmospheric science community (Q2.10, $N = 160$), the majority of the instructor participants (73.8%) indicated that ASER is undervalued, and these results are fairly consistent across demographic categories (including tenure vs non-tenure-track positions). This perceived lack of value placed on ASER is a potential barrier to increased involvement in ASER.

Instructor participants were also asked to assign a level of risk to participating in ASER activities (as outlined in Q1.1) with regard to promotion and/or tenure in their current position (Q2.9, $N = 156$). Participants were not asked to specify risk factors. Thus, perceived risk may be a result of ASER not being aligned with the expectations of their current position, or because ASER is undervalued by their institution/department. Of the 156 instructor participants, 41.7% felt that engaging in ASER presented moderate to significant risk to their prospective promotion and/or tenure. When tenure status is considered (Q4.9), 45.5% of tenured faculty ($N = 55$) and 41.7% of the non-tenure-track faculty ($N = 60$) indicated that ASER work presented a moderate to significant risk to their prospective promotion and/or tenure, with those on the tenure track but not yet tenured ($N = 23$) viewing ASER work as relatively riskier (52.2%; Fig. 3).

Exploring whether perceived risk influenced participants' interest levels in engaging in ASER activities (Q1.1), we found that 77.5% of tenure-track participants indicated a moderate to strong interest in using a website to share or find resources for research-based teaching in the atmospheric sciences, relative to nearly 68% of all participants. Surveywide, the interest in attending a talk or session devoted to education research at a discipline-based conference was 59.5%, with 70% of tenure-track respondents indicated moderate to high interest in this activity. This increases to 82.5% for those who are not yet tenured. Perhaps the most interesting comparison is the number of respondents in each category who indicated moderate to high interest in presenting education research at a discipline-based conference. Surveywide, only 31.9% of the respondents indicated a moderate to high level of interest in this activity. Tenured respondents (N = 80) were only slightly more likely to indicate moderate to high levels of interest in this activity (36.9%), but nearly 61% of those without tenure (but on the tenure-track) indicated moderate to high interest in presenting education research at a discipline-based conference. Only 28.2% of non-tenure-track faculty (N = 73) were interested in presenting education research at a discipline-based conference. These results suggest that, regardless of tenure status, participants are interested in utilizing preexisting ASER resources, but there are substantial differences in the level of interest in directly contributing to ASER-related work.

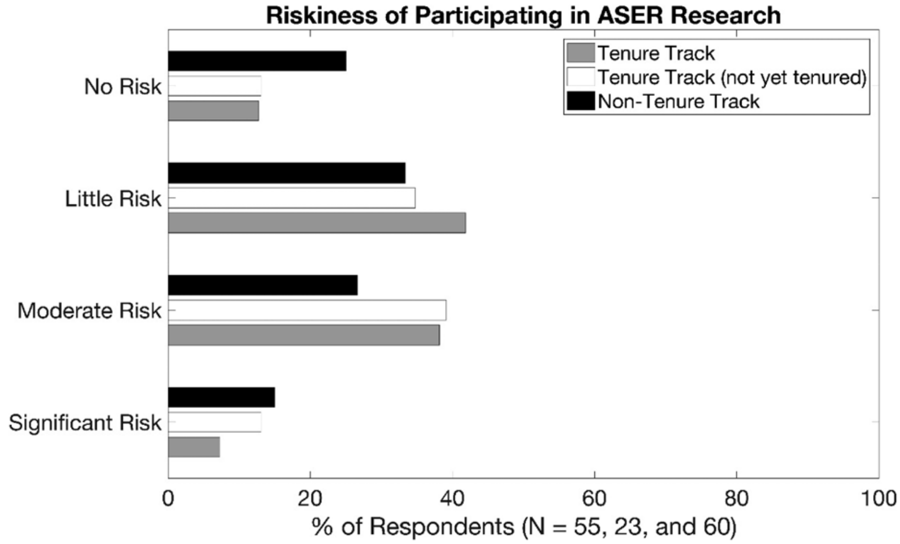

Fig. 3. Survey responses to Q2.9: "Thinking about how the majority of your colleagues value education research, how risky is participating in education research within your current position (with regard to tenure, promotion, overall time allotment, etc.)?" Responses are separated into non–tenure track (black), tenure track but not yet tenured (white), and tenure track (light gray).

The higher level of interest in presenting ASER by tenure-track (not yet tenured) faculty may indicate that engaging in ASER is seen as a way to diversify one's tenure portfolio. It should be noted that successfully transitioning one's research agenda to focus on ASER would require the faculty member to learn novel methods and skills. These are extensive tasks that require time and may not be feasible given the expectations of their current position. Alternatively, the stark differences based on tenure status may be a result of different expectations based on position type and diverse professional identities. Brownell and Tanner (2017) describe a professional identity as how scientists view themselves based on their work and recognition of their endeavors. Since traditional research expectations for a tenure-track employee focus on advancing our understanding of the science rather than advancing the scientific discipline by increasing our knowledge in education, a person with tenure might not want to jeopardize their professional identity by engaging in and presenting education research. Lower levels of interest from non-tenure-track faculty may be due to the fact that this position type often has a higher percentage of teaching and service responsibilities, or perhaps these faculty are seeking a tenure-track position and therefore view a traditional disciplinary research portfolio as more advantageous.

While tenured faculty responses are in line with the responses from all participants on the importance of ASER, a much larger percentage of non-tenure-track faculty (91.5%) and untenured faculty (on tenure-track; 95%) view ASER as moderately to very important. Nearly two-thirds of instructor participants view ASER as undervalued by the community, and this percentage increases to 72.5% when only tenure-track faculty are considered. These results, in concert with the perceived riskiness in ASER, and the perception that ASER conference presentations and papers are not weighted enough for tenure and promotion, may be partially responsible for the present lack of involvement in ASER.

Current resources available

Since DBER requires expertise both in the discipline and in education research, professional development and training experiences can be an important pathway for newcomers to ASER. These events are educational, but they also provide opportunities for collaborations, another means of developing the necessary skills for successfully pursuing ASER (NRC 2012). Therefore, several questions addressed training and professional development resources related to instruction (NRC 2012). For the purpose of this survey, training includes a wide range of experiences from presentations to seminar series in preparation for teaching. Professional development includes workshops and continuing education that occurs after the initial employment period. While these two commonly used terms were not explicitly defined within the survey, examples of training were offered. Five instructor participants noted they were unsure of differences between training and professional development or provided the same response in Q3.1.1 and Q3.2.1 ($N = 96$, $N = 77$). If a respondent included the same answer for both training and professional development, their response was appropriately categorized.

Over three-fourths of instructor respondents (77.6%, $N = 156$) received some form of training, with slightly less (66.7%, $N = 154$) participating in professional development related to instruction (Q3.1 and Q3.2). This demonstrates that nearly 25% of instructor respondents have not had any training related to instruction. Respondents were prompted to elaborate on their most valuable training and professional development experiences in a free-response format. Five leading themes emerged, which are summarized below and in Table 2. Percentages in Table 2 were determined collectively by the authors, where four of the authors individually sorted the free responses into the five themes, then contributed to a group discussion where differences in sorting were debated and resolved. The values should not be expected to add to 100% as free responses frequently fit into more than one theme.

Table 2. Most valuable training and professional development experiences offered by respondents in free response, grouped in leading themes (Q3.1.1 and Q3.2.1).

Themes	Training (%)	Professional development (%)
Longer term	75.8	62.7
Internal	49.5	38.6
External	18.9	28.1
Graduate school	29.8	2.6
Informal	23.5	20.2

Nearly 76% (62.7%) of the instructor respondents indicated that their most valuable training (professional development) experiences had been multipart experiences over time, such as a workshop series or semester-long class related to instruction (Table 2: longer term). These findings are supported by a large body of research which show that the most successful faculty professional development activities allow educators time to process and apply what they have learned, and to receive feedback (Darling-Hammond and McLaughlin 1995; Garet et al. 2001; Holland 2005).

Internal resources are also valued, with 49.5% (38.6%) indicating their most valuable training (professional development) was offered through their home institution (Table 2: internal). Examples of this include teaching assistant orientation for graduate students, workshops offered by a center for teaching and learning, and continuing education and training required for National Weather Service employees. External experiences, such as a conference or workshop [e.g., Earth Educators' Rendezvous, National Aeronautic and Space Administration (NASA) workshop, "On the Cutting Edge" (National Association of Geoscience Teachers)], were the most valuable training (professional development) experience for 18.9% (28.1%) of the respondents (Table 2: external).

The survey data indicated a fourth theme (Table 2: graduate school); high-impact skill development is occurring in graduate school. Though training encompassed a wide range of experiences, from teaching-assistant training to an advanced degree in DBER, nearly 30% of the instructor respondents indicated that their most valuable training experience occurred in graduate school. These results suggest that significant training can, and arguably should, occur while students are preparing for their careers.

Finally, 23.5% (20.2%) of instructor respondents listed informal discussions as their most valuable training (professional development) experience (Table 2: informal). Informal conversations are initiated by the instructor and allow the individual to determine the topic, timing, and duration of the conversation. In contrast, formal opportunities to discuss teaching and learning are not always available to help quickly resolve issues, and they often have a specific agenda (Thomson and Trigwell 2018). Informal conversations and mentoring have been recognized as important professional experiences as they help instructors problem solve, share resources, and discuss novel teaching methods (Pataraia 2014; Poole et al. 2019). It has been shown that instructors tend to seek out other instructors with similar pedagogical views. Thus, it is important to be aware that informal discussions can lead to confirmation bias rather than professional growth as an instructor (Poole et al. 2019).

The survey also identified several formal training and professional development opportunities that are available to the community (Q3.3). Over a third of instructor respondents had access to their home institution's Center for Teaching and Learning (CTL) or Center for Integration of Research, Teaching and Learning (CIRTL; 36%), and nearly one-third (31.2%) reported participating in professional development workshops. A related survey question targeted which of the available resources were actually used. Most instructor respondents reported participating in workshops (28.5%), CTL or CIRTL activities (22.8%), and webinars (16.7%). From these responses, we conclude that CTL and CIRTL resources play an important role in training and professional development, but webinars are also regarded as an important resource.

The survey also explored the level of support for education research endeavors. Instructor respondents were asked whether their institution would provide funding for leading (attending) a conference presentation on education research, roughly 45% (42%) confirmed partial to complete coverage [$N = 151$ ($N = 150$)]. However, at least one-fourth of the instructor respondents (both cases) noted that they would not receive financial support for education research activities, and nearly 30% (33%) said they did not know whether funding would be provided for these activities.

Approximately 20% of the 151 respondents for Q3.9 indicated external funding had been received for an education research project, and roughly 3% had applied but had pending approvals at the time of the survey. The remaining two-thirds had not applied for or were denied funding for their projects. The overwhelming majority of projects were funded by the National Science Foundation (NSF; nearly 66%). While Q3.9 specifically asked for external funding sources, approximately 17% of the respondents used this question to indicate that their home institution provided funding for their education research project, indicating that there are some institutions that are supportive of ASER. Additional funding agencies mentioned were NASA, the National Oceanic and Atmospheric Administration (NOAA), Office of Naval Research (ONR), Federal Aviation Administration (FAA), and industry partners.

When asked if they had ever published an education research article (Q3.10), over 70% of the instructor respondents ($N = 154$) indicated that they had not. For those who had published, outlets included the *Bulletin of American Meteorological Society* (*BAMS*; 28.1%, $N = 18$), the *Journal of Geoscience Education Research* (*JGE*; 21.2%, $N = 14$), and *In the Trenches* (7.8%, $N = 5$). The majority of the respondents (42.2%, $N = 27$) selected the "other" option. This "other" list included nearly 40 different journals with many related to computer science, math, aviation, biology, life sciences, engineering, and physics.

Dolan et al. (2018) notes that it is the responsibility of the individual to communicate the importance of their research; however, in order to support junior faculty through the promotion and tenure process, there is a need for senior faculty and those in leadership positions to learn how to evaluate the impacts of education research, including journal quality. A discipline-specific journal highlighting education research articles, perhaps through a special issue, would improve access to literature on teaching and learning. This would likely lead to increased visibility of ASER related activities and better institutional awareness of the value of this work, potentially reducing the perceived risk and leading to more involvement in ASER (Charlevoix 2008).

Summary

The IPASER survey was developed for a broad range of professionals in the field of atmospheric science to collect data about the size of the ASER community, to highlight the value of ASER to our community, and to identify potential barriers to faculty involvement in ASER. Potential resources to encourage involvement in ASER were also identified. Though largely biased toward academia, the survey results indicate that there is a significant group of educators and professionals that are interested in and value ASER across all stages of their careers and across all demographic categories. There is interest in all facets of ASER; however, the greatest interest lies in a resource to share or find resources related to teaching and learning in atmospheric science, particularly for educators. Despite the interest in ASER activities, many of the instructor respondents perceive at least a moderate level of risk to their promotion and/or tenure potential if they decide to engage in ASER activities through collaborations on teaching and learning research projects and presentations at discipline-based conferences.

The lack of interest in becoming more deeply involved in the ASER community may be a result of a perceived lack of value placed on ASER by their institutions. This includes a lack of funding to support education research, with at least one-fourth of the instructor respondents indicating that they would not be able to receive internal funding to support education research activities, and nearly one-third stating that they were uncertain whether such funding would be available to them. The lack of interest may also result from the fact that successful engagement would require a considerable amount of time and effort for those not formally trained in education research. Furthermore, less than 30% of the ASER articles published by the survey respondents were in discipline-specific journals such as *BAMS*, leading to a lack of visibility of ASER and perhaps contributing (in part) to the lack of participation. These findings highlight additional barriers to participation, as many atmospheric scientists may choose not to engage in ASER due to lack of funding or the perception that it is undervalued by those making decisions for promotion and/or tenure.

These results indicate that while improved access to research-based teaching and learning resources are highly valued by the community, the level to which community members are willing to engage in ASER activities varies significantly and is strongly dependent on an individual's current position. In addition, a perceived lack of value and resources to support ASER are likely preventing broader participation. These results confirm the need for the continuation and expansion of existing support for ASER-related activities and provide guidance for the development and implementation of additional resources to help grow the ASER community.

The most valuable training and professional development experiences related to teaching and learning identified by the participants were external workshops or training in discipline-specific instruction, with longer-term experiences identified as most valuable. In addition, webinars were noted as valuable training and professional development experiences. Professional development experiences have been shown to serve as a pathway to DBER for those with a Ph.D. in the discipline ("border crossers"), particularly for young DBER communities such as ASER (NRC 2012). Additionally, the survey results indicate that many graduate students are being exposed to high-impact training and experiences related to teaching and learning. This is in line with emerging trends in DBER, with recent studies suggesting that one way to grow a DBER community is to integrate more opportunities at the graduate level, including interdisciplinary degree paths (Peffer and Renken 2016; McNeal and Petcovic 2017).

Recommendations

A small-scale interview study of geoscience education practitioners (Feig 2013) identified a perceived lack of recognition, lack of formal training, and a lack of access to education research publications as challenges to a successful education-research-focused career. Their suggestions to address the barriers are in line with our survey findings in that there is a need for 1) more training for those interested in pursuing careers in education research, 2) a need for the development of evidence-based resources for those hoping to use education research findings in their classrooms, and 3) a need for better access to literature on teaching and learning in the discipline. Furthermore, despite the widespread availability of research-based teaching strategies, university science courses in general have been slow to change. Research has shown that significant changes to teaching practices are more likely when support structures and feedback mechanisms are present, which is easier to incorporate into longer-term training and professional development opportunities (McLaughlin et al. 2010; Rutz et al. 2012; Gormally 2017; Stains et al. 2018).

The environments in which instructors work also play a vital role in their ability to effect change (Manduca 2017). Research demonstrates that there are certain features of a system (e.g., department or institution) that are vital to bringing about a change in culture that is supportive of reflective, scholarly teaching. Specifically, systems set the culture for everything from learning spaces to reward structures (Anderson et al. 2011; Manduca 2017; Fisher and Henderson 2018). Thus, it is imperative that ASER community members are supported by those in leadership positions, and efforts to increase the awareness of ASER and its value to the system are needed to reduce the perceived risk.

Based on these survey results, and keeping in line with existing research on pedagogical change, we make the following recommendations for improving atmospheric science education (both formal and informal) through research:

1) Improve access to ASER literature for all atmospheric science educators. This will increase the visibility and legitimacy of ASER.
2) Provide longer-term training and professional development opportunities for those interested in formally pursuing ASER, including broadening access to existing offerings, and developing interdisciplinary ASER degree paths.
3) Recognition of ASER by professional societies, organizations, and institutions, broadly and at the individual level. Increased support should lead to more ASER funding opportunities, both internal and external.
4) Develop venues of support for ASER scholars; this includes facilitating collaborations, and encouraging the use of evidence-based teaching and learning practices.

The NRC (2012) describes the evolution of various DBER fields that have overcome many of the barriers described in this paper (e.g., physics, chemistry, biology, and engineering). Successful strategies have included policy statements by disciplinary societies that recognize the importance of education research [e.g., The American Physical Society (APS) “Research in Physics Education” policy statement issued in 1999], symposia at national meetings dedicated to education research, and conferences devoted to DBER (e.g., Chemistry Education Research and Practice Conference; NRC 2012). Journal supplements highlighting education research have been shown to increase visibility and legitimacy of DBER, and several disciplines now have entire journals dedicated to education research in their field (NRC 2012). Some disciplines have developed online communities that distribute resources on education research and professional development opportunities, and foster education research collaborations (e.g., "On the Cutting Edge" in the geosciences, and the "Collaboratory for Engineering Education Research" in engineering; NRC 2012). The future success of an emerging DBER field is dependent upon increasing visibility, recognition, providing funding for training and research, and establishing community. The recommendations outlined here provide a clear path forward for ASER, setting the foundation for increased collaboration in ASER and ultimately for improved education in the field of atmospheric sciences.

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