Comparative Study of High-Quality Professional Development for High School Biology in a Face-to-Face vs Online Delivery Mode

Susan Yoon, University of Pennsylvania, yoonsa@upenn.edu
Katherine Miller, University of Pennsylvania, kmmiller@gse.upenn.edu
Thomas Richman, University of Pennsylvania, trichman@upenn.edu
Daniel Wendel, Massachusetts Institute of Technology, djwendel@mit.edu
Ilana Schoenfeld, Massachusetts Institute of Technology, ilanasch@mit.edu
Emma Anderson Massachusetts Institute of Technology, and eanderso@mit.edu

Abstract: Online professional development (PD) can support broader accessibility than traditional face-to-face PD. However online delivery presents challenges for known characteristics of high-quality PD, such as collaborative knowledge building and community development, that have proven positive outcomes in face-to-face modes. To date, there have been few comparative studies that demonstrate equivalent outcomes when activities have been translated from a successful face-to-face implementation to an online format. This study investigates whether online PD can achieve the same impact for high school biology teachers and students using computer-supported complex systems curriculum and instruction. We articulate changes in design decisions to accommodate the online mode and measure impact on teachers' perceptions of their experiences and student outcomes. The results show positive teacher perceptions in both PD formats and roughly equal student outcomes. However, teachers articulated other benefits to online activities that indicate opportunities for improved access to high-quality PD.

Introduction

There is a need for high-quality professional development (PD) for science education that is accessible to a diverse and wide ranging audience of teachers (Fischer et al., 2018; Wilson, 2013). Science teachers face a steep learning curve with the global shifts toward a greater focus on the application of scientific knowledge and skills (European Commission, 2015; NRC, 2012). Research has shown that high-quality PD can improve teachers' practice and have a positive impact on student outcomes (e.g., Desimone & Garet, 2015; Fischer et al., 2018). However, for many teachers who are geographically isolated, access to high-quality PD is a primary limiting factor in their professional growth and ability to address the changing landscape of science education (Peltola, 2017; Wei et al., 2009). For these teachers, face-to-face PD is often not an option. As Hill (2015) and others have noted, traditional face-to-face PD is expensive and limited in its ability to scale. Offering PD online is a rapidly growing option that can support broader accessibility anywhere, anytime at lower costs (Dede at al., 2019; USDOE 2010). Yet, despite its promise, there are challenges in designing for high-quality PD with proven known best practices in the face-to-face mode that include social learning and collaborative knowledge building (Dede, 2009; Moon et al., 2014). A report by the US Department of Education (2010) suggests that online PD can provide a more accessible option if it can be shown to be as effective as face-to-face PD. In one such study, Fishman et al. (2013) found that PD offered online can be as successful as face-to-face modes in promoting improved teacher knowledge, classroom practice, and student outcomes. However, there is a lack of similar studies that directly compare effectiveness in both formats despite calls for increased research in this area (Moon et al., 2014; USDOE, 2010). This current study seeks to help fill this gap.

From 2010 to 2014, our team engaged in developing and delivering face-to-face PD to high school biology teachers using computer-supported complex systems curriculum and instruction. This work was built on known characteristics of high-quality PD for science teachers. Findings from several studies (e.g., Yoon et al., 2016; 2017) revealed high teacher satisfaction, curricular utility, and increased student participation and learning outcomes. The success of this project encouraged us to consider how to scale this work to reach more teachers. We consulted recent reports on the lack of high-quality teacher PD that implicated time and space as issues related to scale (Merritt, 2016). Combined with issues of access, this led to a plan to move the PD to an entirely online space. We chose edX as the platform, due to its existing mechanisms to reach large numbers. The PD was recreated in this space, staying true to the objectives and basic structure of the face-to-face PD, while including adaptations in-line with best practices for online learning (e.g. Booth 2012; Dede et. al., 2019; Yuan & Kim, 2014). In the research reported here, we compare the results from the face-to-face PD to a pilot run of the online course.

Theoretical considerations

Designing high-quality PD

The field is developing best practices for designing and implementing high-quality PD (e.g., Desimone, 2009; Gerard et al., 2011). These practices include a focus on relevant and useful content, eliciting and capitalizing on teachers' existing knowledge and skills, engaging teachers in active learning, allowing teachers time and space for reflection, and supporting collaboration. Gerard and colleagues (2011) also point out the importance of mentoring and access to expertise through facilitators and more senior teachers. We know that optimal learning starts with teachers as knowers and agents of change where social relationships are fostered and where the examination of subject-matter pedagogy involves active sense making and problem solving (Cochran-Smith & Lytle, 1999; Moon et al., 2014). In order to create a space for active knowledge building and collaboration in an online course, scaffolded social forums where teachers can interact with one another and build on each other's knowledge and expertise are needed. Zeichner and Liston (2014) highlight the importance of building social forums for discussing ideas in leading to change in teachers' practice. Likewise, Booth (2012) found that social learning was essential in building knowledge and trust among teachers. Other studies have demonstrated that collaboration can increase knowledge creation and sharing in an online space (e.g., Dede, 2009). Additional best practices specific for online learning and collaboration have been investigated, such as the use of open-ended questions that encourage participants to share thoughts rather than provide facts (Ng et al., 2012) and case-studies (e.g. videos of classroom implementation) that allow for shared experiences (Yuan & Kim, 2014). However, more research is needed in order to determine whether and how online PD is a viable alternative to face-to-face PD (Dede, 2009; USDOE, 2010).

Benefits of online PD

Some research has already illustrated the benefits of conducting PD online. It allows for greater geographical diversity among participants and reduces transportation time and costs, as teachers can access online PD courses from anywhere (Bates, Phalen, & Moran, 2016). Specifically, asynchronous online PD provides learners with the ability to self-pace and access materials at flexible hours. Evidence suggests this time flexibility is particularly appealing to PD participants, especially when teaching schedules do not allow for attendance in face-to-face programs (e.g., Parsons et al., 2019). Online PD also has the potential to reduce the overall cost of PD implementation when online resources are used repeatedly and participants are geographically dispersed (Fishman et al., 2013). Other researchers have hypothesized that online PD offers a natural avenue for developing and supporting online teacher communities in the longer term, which can help teachers continually reflect on and adapt their teaching practices (e.g., Frumin et al, 2018). Dede and colleagues (2019) and others discuss the fact that online PD seems well-positioned to take advantage of many of the benefits brought about by learning engineering and other advancements in online educational platforms.

Previous studies and the aforementioned potential notwithstanding, there still remains the issue of limited empirical research directly comparing the outcomes of online versus face-to-face PD in order to show that online PD can be as effective for teachers. Fishman and colleagues (2013) used a randomized experiment to examine the differences between secondary school teacher and student learning outcomes resulting from a PD delivered face-to-face and asynchronously online. Teachers from both PD groups exhibited similar increases in content knowledge and feelings of self-efficacy, with only minor differences in changes to classroom practices. Student performance also increased comparably across both groups. Despite these promising results, Moon and colleagues (2014) cautioned against over generalization from this study and recommended additional research into the nuanced trade-offs that exist between online and face-to-face PD. Other studies examining online versus face-to-face adult learning programs in professional and academic settings have suggested that outcomes from online PD could compare favorably with face-to-face PD, but further experimental research is needed (e.g., Kissau, 2015; Olivet et al., 2016). Recent studies have shown that teachers are readily participating in online PD activities, Parsons and colleagues (2019) conducted a survey with 258 teachers across 41 US states and found that the majority of respondents had participated in online PD opportunities. Given that, understanding whether online PD can foster equivalent teacher learning and instructional outcomes is even more of an imperative. This study asks the following research question: To what extent are online PD experiences comparable to face-to-face, in relation to a) teachers' perceptions and b) student learning outcomes?

Methods

To address the research question, we use a comparative mixed methods approach to analyze differences in teacher perceptions of the PD delivery and subsequent student learning outcomes when teachers accessed the same curriculum through a face-to-face versus an online asynchronous PD platform.

Context

This study is part of a long-standing program of research funded by the U.S. National Science Foundation that undertakes the design and dissemination of a curriculum to teach common topics in high school biology through complex systems simulations (Yoon et al., 2016; 2017; 2018). The curriculum includes five units on the topics of Genetics, Evolution, Ecology, the Human Body, and Animal Systems. They entail working with the agent-based simulation tool and include experiences in core scientific practices as outlined in the Next Generation Science Standards, such as analyzing and interpreting data, engaging in argument from evidence, and obtaining, evaluating and communicating. Students normally work in groups of two to complete the units and the materials for each unit take two to three days to complete. The design of the curriculum was conducted along-side the PD activities described in the following section.

Face-to-face

The face-to-face version of the PD (1.0) ran for two iterations between 2012 and 2014. We provide a brief summary here (for further details see Yoon et al., 2016; Yoon & Baker-Doyle, 2018). The participants attended 80 hours of programming over two consecutive years, with a 30 hour week-long summer workshop during August of each year and 10 additional hours in weekend workshops during the school year. The PD was designed to align with known characteristics of high-quality PD (Desimone, 2009): (a) aligned content; (b) active learning opportunities; (c) coherence with professional demands; (d) at least 20 hours in duration and spread over a semester; and (e) collective participation of teachers from the same school, grade, or subject. We focused especially on active learning as a way to support teachers in learning and implementing new technologies, a known challenge for teachers. During each summer of the PD, teachers completed the units from the curriculum in pairs, to experience the curriculum as a learner, and participated in additional activities that engaged them in reflecting on the experience and brainstorming how to support students in implementation. We supported collaboration by working with specific content and age level teachers in high school biology, several of whom were from the same schools, which allowed them opportunities to address coherence with professional demands. During each school year, participants conducted at least four of the curriculum units with their students.

The first year–2012-2013, which we refer to as iteration 1.1, focused on the content and pedagogy of the curriculum with participating teachers acting as co-designers in iterative improvement to the simulations and supporting student and teacher materials. The second year–2013-2014, which we refer to as 1.2, included a greater focus on increasing collaboration and relationship building among the teachers in the PD. This iteration also included more supports for learning complex systems structures and processes based on feedback from the first year (see Yoon & Baker-Doyle, 2018) for details of the design improvement outcomes). Both iterations of 1.0 were used as comparison to the online implementation because they provide information about how to improve the curriculum materials and how to work with teachers as a community—both elements of high-quality PD.

Online

The online version of the PD (2.0) ran July 2018 through June 2019. It was designed to create a similar space for fostering social relationships to engage in active sense making as the face-to-face PD provided. Based on results and feedback from 1.0 (Yoon et al., 2017), researchers found five categories of supports that the teachers found most important for their learning from the PD: a) time and experience; b) hands-on-practice and training; c) just-in-time supports; d) interaction and building knowledge within the community; and e) supporting teacher beliefs. The online PD was designed to provide these supports, while modifying the in-person activities and discussions for online delivery. For example, in order to provide hands-on practice and training, detailed walk-through videos with voice-over instruction were recorded to provide online teachers with support to practice the simulations on their own. Additionally, while the face-to-face PD teachers presented problems of practice from their classroom implementation and had in-person discussions about strategies in order to build knowledge and support teacher beliefs, participants in the online PD watched videos of teachers from 1.0 teaching the units in their classrooms and discussed strategies on a discussion forum that included the experienced teachers as active members.

The above modifications were made intentionally to maintain the objectives of the PD, the characteristics of high-quality PD, and the supports that were important to teachers in 1.0. In order to guide this transition and oversee consistency, three teachers from the 1.0 iteration acted as design collaborators for 2.0. They worked with the research and design team to provide insight on how well the online version compared to the in-person version of the PD. The online course consisted of 7 modules and was designed to encompass 40 hours of instruction to be completed over a six-week period. Additionally, three one-hour video meet-ups were held during the school year.

Population

The participants in each iteration of the study were recruited through the researchers' networks and were primarily

a sample of convenience, though they represent many diverse classroom contexts.

Face-to-face

Iteration 1.0 of the PD included 10 teachers, seven women and three men, from a metropolitan area in the northeastern U.S. The years of experience for the teachers ranged from 3.5 - 19 years, with an average of 8 years. The schools they taught at were all public schools but ranged in demographics with one school being almost entirely white (3% minority) and another with 71% ethnic minority. The socio-economic demographics were also wide ranging, with school measurements of low-income students ranging from 14% to 59%. Across the 10 participating teachers' classrooms, over 300 students were reached each year with 354 participating in research in 1.1 and 361 participating in 1.2. See previous results for more detailed demographic information on teachers (Yoon et al., 2017; Yoon & Baker-Doyle, 2018) and schools and students (Yoon et al., 2016, 2017) for 1.0.

Online

For the online PD, 8 teachers from 6 different schools in 3 different metropolitan areas in the northeastern U.S. participated in the course. The teachers have a range of 0 – 20 years of teaching experience with an average of 8.3 years. The least experienced teacher had just finished pre-service teaching the spring before the course was administered. The teachers were employed mainly in public schools with the exception of one independent school. Three of the teachers taught at the same school and the other five were each at one of the other schools. The demographics of these schools also demonstrated diversity. The most diverse school had 82% ethnic minority, while the least diverse had 19%. The percentage of low-income students ranged from 62% to less than 5%. Five of the participating teachers agreed to collect data on their students and, with some attrition, resulted in data from 88 participating students for the 2.0 dataset.

Data collection

The research goal was to compare two different modalities for delivering PD for complex-system curriculum. To investigate this research goal, data from four different sources were collected from each of the three iterations of the PD: teacher post-course satisfaction surveys, teacher post-implementation interviews, and student pre- and post-implementation content and study surveys.

Upon completion of the PD summer course, teachers were administered a PD satisfaction survey to measure their perceptions of the PD. This comprised 18 5-point Likert-scale (1=strongly disagree to 5=strongly agree) questions that probed their experiences with the course resources in the areas of overall course satisfaction (e.g., *The course covered topics that are relevant to the grade(s) I teach*); module construction and delivery (e.g., *The modules actively engaged those in attendance*); and usability of materials in specific teaching activities (e.g., *The student worksheets given out during the course will be useful in my teaching*). The survey also included 10 open-ended questions that asked teachers to describe what they did and did not like about the course.

Individual post-implementation interviews were conducted with teachers to gather information about how they implemented the curriculum in their classrooms and how participation in the course prepared them to do so. The semi-structured interview questions were constructed to probe the extent to which they felt prepared and supported to teach the curriculum (e.g. *Which aspect of the PD did you find the most useful for your teaching?*). Additionally, they were asked about their perceptions of the online course (e.g. *How did this experience compare with other online PD in which you've participated?*) Questions also probed for their external challenges and support for implementation (e.g. *Were there contextual variables that made it more or less challenging to implement the curriculum; Do you feel you received adequate support from the BioGraph team?*) Individual interview lengths ranged from 22 to 42 minutes and the audio-recorded interviews were transcribed.

Students completed two surveys pre-implementation and two surveys post-implementation. The content knowledge survey consisted of 14 multiple choice questions about biology content (e.g. *There are many different enzymes located in the cytoplasm of a single cell. How is a specific enzyme able to catalyze a specific reaction?*) and 1 open-ended question about complex systems (*Imagine a flock of geese arriving in a park in Philadelphia, where geese have not lived before. Describe how the addition of these geese to the park may affect the ecosystem over time. Consider both the living and nonliving parts of the ecosystem.*). The study survey consisted of 44 5-point Likert-scale (1=strongly disagree to 5=strongly agree) questions that probed students' experiences with learning science in the classroom (e.g. *I often work together with other students to learn about science; I use computer technologies to share information about science.*)

Data analysis

We identified overarching trends and triangulated findings between the three data sources. For the satisfaction surveys, average Likert-scale responses were calculated for all 18 items and then aggregated in the three areas of:

overall course satisfaction, module construction and delivery, and usability of materials in specific teaching activities. The averages for all three iterations of the PD were compared for equivalence in the three areas across the three years. The teacher interview transcriptions were qualitatively mined for comments and insights that offered support for the findings from the surveys.

The student multiple choice content questions were scored, and then compared from pre- to post-implementation for each year using a paired t-test to see if the average scores changed from the beginning to the end of the curriculum implementation. To understand the amount of impact, we calculated the effect size (Cohen's *d*). The open-ended complex systems questions were scored on a scale of 1 (clockwork framework) to 3 (complex systems framework) on four different parameters: predictability, processes, order, and emergence and scale. For more information on this coding scheme and data analysis for iteration 1.0 see Yoon et al. 2017. The 2.0 data was coded by two researchers who were trained on the coding manual by a researcher who conducted the analysis of the 1.0 data. The two researchers then coded 23% of the responses (30 out of 132 pre and post responses) independently. An interrater reliability of .88 was achieved. One of the researchers then coded the remainder of the responses. The results of this coding were then compared using a paired t-test of total scores out of 12 from pre to post implementation. Averages were found for the Likert-scale responses for the student study survey which were also analyzed using paired t-tests to determine whether average scores changed from pre to post implementation.

Findings

The findings from this research show that results from the online course for both teacher perceptions and student outcomes were equivalent and even slightly better than results from the first year of face-to-face PD. The online PD outcomes, although very close, were not as good as the second year of face-to-face PD.

Teacher perceptions of online delivery indicate opportunity for accessible PD

The teachers' perceptions of their experience show that the online delivery mode for the PD had roughly equivalent results to the first year of face-to-face mode but was not quite as effective as year 2. Findings from the satisfaction survey showed that teachers in the online PD had a very positive experience, rating all 18 Likert-scale items on average between 4.5 and 5. Aggregate averages in the areas of overall course satisfaction, module construction and delivery, and usability of materials were 4.60, 4.69 and 4.70 respectively. These findings were roughly comparable to those found in iteration 1.1 of the face-to-face PD (4.73, 4.78, 4.66) but slightly less than iteration 1.2 (4.95, 4.98, 4.84). In the category of usability of materials, the online teachers rated items as higher than the teachers in the first year of face-to-face PD (4.70 for online, compared to 4.66 for iteration 1.1 of face to face), which is significant because those items ask whether the specific teacher resources (learned about and acquired online) would be helpful to their instruction. The lower rating in the area of overall course satisfaction could be explained by comments that indicated ways to improve the online experience. One teacher wrote,

> *The biggest challenge I had was that there were no deadlines for each module. I understand that is difficult to do in the summer, but I don't feel like I got the most out of the discussions because I was so far ahead of everyone else.* [But] *I loved the convenience of doing it all online. Because I had free time, I worked through the modules quickly and often times, I was the first one. I had no other comments to look at or reply to. It was a while before others started doing the modules. I tried to go back and read/reply to comments, but it was difficult since I had done some of the modules weeks prior.*

This teacher still articulated the convenience of "doing it all online" with the flexibility of going through the PD during the summer when there was more free time. Another teacher talked about ways to overcome isolation but similarly noted her enjoyment of the course.

> *I don't have a good answer for this! Live, web-based meetings might help overcome the isolating effects of the MOOC format; there were opportunities for social interactions within the forums, but I never felt quite connected to my colleagues. I wonder if developing our social ties might improve this aspect of our experience. Regardless, I very much enjoyed this course.*

The higher rating of the usability of materials was supported by enthusiasm shown in teachers' interviews. Multiple teachers said that the curriculum fit well into their existing Biology course. One teacher said,

> *I already do these topics. So, on a day where I might have done a different activity, I can just*

do this instead. So, I love that part of it. I feel like this is actually doable.

This teacher highlighted the usability of the materials as replacements for existing activities. Another teacher supported this excitement saying that the new curriculum might facilitate learning better than her old way of teaching, while also commenting on the computer science aspect of the curriculum.

> *This is like just stuff that fits exactly into my curriculum…I'm getting pretty excited about kind of changing my curriculum in a way that hopefully facilitates the learning a little better but also kind of filling that need for computer science.*

These comments show that while the online delivery mode had room for improvement with teacher experience, the teachers were enthusiastic about using the curriculum materials and felt ready to do so.

Similar student outcomes for face-to-face and online PD delivery modes

Student outcomes were measured in three areas through two survey tools. The results from iteration 2.0 are compared here to the results from the first two iterations, which can also be found in more detail in Yoon et al. (2017). Students' content knowledge in biology improved significantly for all three iterations of the PD (Table 1) with medium effect sizes for the two iterations of the face-to-face PD (d = 0.56 and 0.67) but only a small to medium effect size (d = 0.36) for the online PD. Students' understanding of complex systems also improved significantly for all three iterations of the PD (Table 2). Here, the online PD actually showed a greater effect size (d = 0.38) than the first year of the face-to-face PD, which had only a small effect (d = 0.19).

With respect to the student study survey measuring students' perceptions of their learning, there was a significant positive increase in all three iterations of the PD (Table 3) with the online PD showing a greater effect size than year 1 of the face-to-face PD but not as high as year 2. Of note, the data shows similar pre-test averages and standard deviations for all three measures across the three iterations, which suggests some level of equivalence for the populations being measured. These results show that online delivery of PD can have comparable student outcomes to PD delivered face-to-face.

Table 1: Results of student biology content knowledge surveys

Iteration	Pre-test Avg*	Post-test Avg*	Difference	t value	df	p value	Cohen's *d*
1.1	6.71 (2.31)	8.13 (2.78)	1.42	10.73	362	<0.001	0.56
1.2	7.67 (2.36)	9.43 (2.47)	1.76	12.50	345	<0.001	0.67
2.0	7.63 (2.46)	8.50 (2.42)	0.87	3.69	87	<0.001	0.36

* Scores are out of 14.

Table 2: Results of student complex system content knowledge responses

Iteration	Pre-test Avg*	Post-test Avg*	Difference	t value	df	p value	Cohen's *d*
1.1	6.18 (1.48)	6.51 (1.49)	0.33	3.51	353	<0.001	0.19
1.2	5.80 (1.23)	6.79 (1.29)	0.99	12.26	360	<0.001	0.65
2.0	5.95 (1.25)	6.51 (1.51)	0.56	2.62	63	<0.05	0.38

* Scores are out of 12.

Table 3: Results of student study survey responses

Iteration	Pre-test Avg*	Post-test Avg*	Difference	t value	df	p value	Cohen's *d*
1.1	3.44 (0.48)	3.63 (0.56)	0.19	6.86	320	<0.001	0.36
1.2	3.51 (0.44)	3.80 (0.45)	0.29	11.54	309	<0.001	0.67
2.0	3.77 (0.41)	3.94 (0.42)	0.17	3.35	80	<0.01	0.41

* Scores are out of 5.

Discussion

The goal of this project was to examine the viability of scaling access to high-quality PD at low to no cost by adapting a successful face-to-face PD to an online delivery mode. Some of the strongest barriers to teachers' professional growth are access to expertise and resources and time constraints (Merrit, 2016; Peltola, 2017). Through moving PD online, scaling costs can be cut while simultaneously increasing access for those with time and geographic constraints. Though some previous studies (e.g. Fishman et al., 2013; Kissau, 2015) have suggested that online PD can be just as effective as face-to-face, more direct comparison research is needed to support these findings (Moon et al., 2014). This study adds to this existing research with additional evidence that online PD can be as effective as face-to-face PD. Previous research has shown that more time and training with a curriculum leads to stronger and more sustained change and that two years is an ideal time for PD (Yoon et al., 2017; Gerard et al., 2011). This can potentially explain the higher outcomes from year 2 of the face-to-face PD. The outcomes from the online delivery were comparable, and in some cases even better than the outcomes from year 1 of the face-to-face PD. This suggests that though extended time is beneficial to teachers, similar results can be achieved in the same amount of time whether the PD is delivered online or face-to-face.

Although overall outcomes were roughly comparable across the different iterations of the PD, our findings indicate that several of the affordances and weaknesses of online PD identified in the literature (Booth 2012) were borne out in our study. While we aimed to foster knowledge building through interaction among participants by using intentionally designed discussion prompts and facilitation, teachers identified forging connections in the online environment as a challenge. The asynchronicity of the discussion board proved especially problematic for some teachers due to the delay between posts and responses. In future iterations, a more defined timeline for completing modules and posting in the discussion board may help reduce this difficulty. Additionally, increasing the number of participants in the discussion board may decrease the response time for replies, as more participants will be participating in the discussion board at any given time. However, too many participants will likely make the community and relationship building more difficult. Despite these issues, the participants found the general flexibility of accessing online resources and completing self-paced modules valuable. Teachers will continue to benefit from this flexibility as the resources will remain readily available online well beyond the completion of the PD. Furthermore, in future iterations of the online PD, development of a continuously available discussion forum could allow past participants in the online PD to learn from their peers by asking and answering implementation questions in the years following the program.

A limitation of this study is the relatively small sample size of students for the online delivery. Though there were a similar number of teachers participating, fewer of them agreed to collect data on their students. As such, more extensive analysis of the student outcomes and comparison to the outcomes from the face-to-face PD as reported in Yoon et al. (2017) was not possible. However, one of the primary benefits of an online delivery mode is its ability to reach a larger number of teachers. This past summer of 2019, the course was launched on edX enrolling 260 teachers in 20 countries and 17 US states with a 16% completion rate (41 teachers). Additional data is being collected on a subset of these teachers and their students in order to provide a more robust data set for comparison with the face-to-face data. As suggested by the US Department of Education (2010), if online delivery modes can be shown to be as effective as face-to-face at delivering high-quality PD, they offer an efficient alternative that both reduces cost and increases access to growth opportunities for teachers.

References

Bates, M. S., Phalen, L., & Moran, C. (2016). Online professional development: a primer. *Phi Delta Kappan*, *97*(5), 70–73.

Booth, S. E. (2012). Cultivating knowledge sharing and trust in online communities for educators. *Journal of Educational Computing Research, 47*(1), 1-31.

Cochran-Smith, M., & Lytle, S. L. (1999). Chapter 8: Relationships of knowledge and practice: Teacher learning in communities. *Review of research in education*, *24*(1), 249-305.

Dede, C., Ketelhut, D.J., Whitehouse, P., Breit, L., & McCloskey, E.M. (2009). A research agenda for online teacher professional development. *Journal of Teacher Education*, *60*(1), 8-19.

Dede, C., Richards, J., & Saxberg, B. (Eds.). (2019). *Learning Engineering for Online Education: Theoretical Contexts and Design-Based Examples*. New York: Routledge, Taylor & Francis Group.

Frumin, K., Dede, C., Fischer, C., Foster, B., Lawrenz, F., Eisenkraft, A., … Mccoy, A. (2018). Adapting to large-scale changes in Advanced Placement Biology, Chemistry, and Physics: the impact of online teacher communities. *International Journal of Science Education*, *40*(4), 397–420.

Darling-Hammond, L., Hyler, M. E., Gardner, M. (2017). *Effective Teacher Professional Development.* Palo Alto, CA: Learning Policy Institute.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better

conceptualizations and measures. *Educational Researcher, 38*, 181–199.
Desimone, L., & Garet, M. S. (2015). Best practices in teachers' professional development in the United States. *Psychology, Society and Education, 7*(3), 252-263.
European Commission (2015). Science education for responsible citizenship. European Union: Directorate-General for Research and Innovation Science with and for Society.
Fischer, C., Fishman, B., Dede, C., Eisenkraft, A., Frumin, K., Foster, B., … McCoy, A. (2018). Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science reform. *Teaching and Teacher Education*, *72*, 107–121.
Fishman, B., Konstantopoulos, S., Kubitskey, B. W., Vath, R., Park, G., Johnson, H., & Edelson, D. (2013). Comparing the impact of online and face-to-face professional development in the context of curriculum implementation. *Journal of Teacher Education*, *64*(5), 426-438.
Gerard, L., Varma, K., Corliss, B., & Linn, M. (2011). Professional development for technology-enhanced inquiry science. *Review of Educational Research*, *81*(3), 408-448.
Hill, H. (2015). Review of *The Mirage: Confronting the hard truth about our quest for teacher development*. Boulder CO: National Education Policy Center.
Kissau, S. (2015). Type of instructional delivery and second language teacher candidate performance: online versus face-to-face. *Computer Assisted Language Learning*, *28*(6), 513–531.
Merritt, E. G. (2016). Time for teacher learning, planning critical for school reform: Students aren't the only ones who need more time to learn; teachers also need more and better time for learning and for planning. *Phi Delta Kappan*, *98*(4), 31.
Moon, J., Passmore, C., Reiser, B. J., & Michaels, S. (2014). Beyond comparisons of online versus face-to-face PD: Commentary in response to Fishman et al., "Comparing the impact of online and face-to-face professional development in the context of curriculum implementation". *Journal of Teacher Education*, *65*(2), 172-176.
National Research Council. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century.* Washington, DC: The National Academies Press.
Ng, C.S.L., Cheung, W.S. and Hew, K.F. (2012), Interaction in asynchronous discussion forums: peer facilitation techniques. *Journal of Computer Assisted Learning, 28*, 280–294.
Olivet, J., Zerger, S., Greene, R. N., Kenney, R. R., & Herman, D. B. (2016). Online Versus Face-to-Face Training of Critical Time Intervention: A Matching Cluster Randomized Trial. *American Journal of Distance Education*, *30*(4), 237–249.
Parsons, S. A., Hutchison, A. C., Hall, L. A., Parsons, A. W., Ives, S. T., & Leggett, A. B. (2019). U.S. teachers' perceptions of online professional development. *Teaching and Teacher Education*, *82*, 33–42.
Peltola, P., Haynes, E., Clymer, L., McMillan, A., & Williams, H. (2017). *Opportunities for teacher professional development in Oklahoma rural and nonrural schools* (REL 2017–273). Washington, DC: U.S.
The New Teacher Project (2015). *The mirage: Confronting the hard truth about our quest for teacher development*. Washington, DC: Authors.
U.S. Department of Education, Office of Planning, Evaluation, and Policy Development (2010) *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies,* Washington, D.C.
Wei, R. C., Darling-Hammond, L., Andree, A., Richardson, N., & Orphanos, S. (2009). Professional Learning in the Learning Profession: A Status Report on Teacher Development in the US and Abroad. Technical Report. *National Staff Development Council*.
Wilson, S. M. (2013). Professional development for science teachers. *Science, 340,* 310-313.
Yoon, S. A., & Baker-Doyle, K. J. (2018). *Networked by Design: Interventions for Teachers to Develop Social Capital*. New York, NY: Routledge.
Yoon, S., Anderson, E., Koehler-Yom, J., Evans, C. Park, M., Sheldon, J., … Klopfer, E. (2017). Teaching about complex systems is not a simple matter: Building effective professional development for computer-supported complex systems instruction. *Instructional Science, 45*(1), 99-121.
Yoon, S., Klopfer, E., Anderson, E., Koehler-Yom, J., Sheldon, J., Shoenfeld, I., … Goh, S. (2016). Designing computer-supported complex systems curricula for the Next Generation Science Standards in high school science classrooms. *Systems, 4*(38), 1-18.
Yuan, J. and Kim, C. (2014), Guidelines for facilitating the development of learning communities in online courses. *Journal of Computer Assisted Learning, 30*, 220–232.

Acknowledgments

This project is funded by the National Science Foundation Grant #827647.