Emerging Design Principles for Online and Blended Teacher Professional Development in K-12 STEM

Community for Advancing Discovery Research in Education

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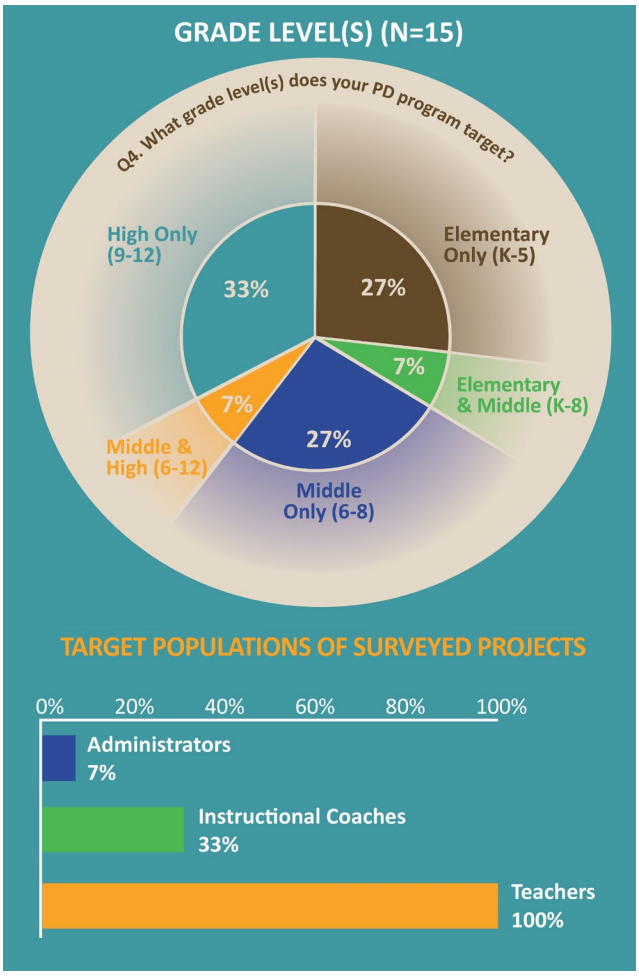
Introduction

Online modes of teacher professional development (PD) have gained prominence in recent years for their potential to transform and expand access to high-quality resources and experiences that positively impact teachers' knowledge, beliefs, instructional practices, and ultimately, student learning. Program developers, administrators, and teachers may turn to online venues for professional learning for a number of reasons, including to scale up face-to-face models; increase access to high-quality programs that aren't available locally; and/or take advantage of innovative technologies such as simulations that provide new modalities for teacher learning. Online learning experiences vary in their program format, goals for teacher learning, duration, and leveraged technologies. They may take place entirely online or, in the case of blended PD programs, in conjunction with face-to-face activities. However, with the increasing demand for and availability of online offerings, there is still much to be learned about the effectiveness of these programs and the factors that contribute to their success.

Online and Blended PD in DRK-12

The National Science Foundation's (NSF) Discovery Research PreK–12 (DRK–12) program, which "seeks to significantly enhance the learning and teaching of science, technology, engineering, mathematics and computer science (STEM) by preK–12 students and teachers, through research and development of STEM education innovations and approaches," is poised to contribute in this area (NSF, 2017, p. 1). In fall 2016, CADRE (the resource network for NSF's DRK–12 program) identified 26 active projects in the DRK–12 portfolio that were researching and/or developing online or blended teacher PD programs.[1] Representatives from 15 projects responded to a survey on their work in this area. The results from these 15 projects are summarized below.



Content and Grade Level Focus

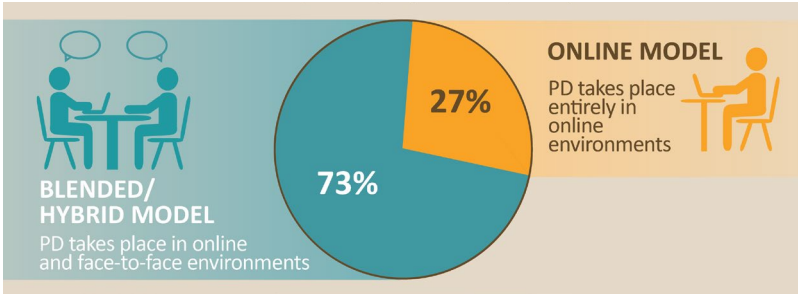
The surveyed projects are working across STEM and computer science disciplines, with nearly three-quarters focusing exclusively on either math or science. Thirty-three percent of these projects target high school only, 27% target middle school only, and 27% target elementary school only. The remaining ~14% target multiple grade bands.

Target Audience

While all survey respondents indicated that their PD is targeted toward teachers, 40% are also targeting administrators or instructional coaches.

[1] See Appendix A.

PD Format



Seventy-three percent of respondents indicated that their projects include a blended PD model with the remaining 27% using an online-only model. Respondents primarily reported that the online component of their PD will be used to provide access to information (87%), to engage in asynchronous discussion (80%), and to share content or products they developed (80%). Projects are using a variety of technologies, with nearly all leveraging communication tools (93%; e.g., electronic mailing lists, discussion forums, videoconferences), and more than half leveraging multimedia resources (73%; e.g., video, animations) and learning management systems (60%; e.g., Canvas, Blackboard).

About this Product

Between February and September 2017, awardees representing 11 projects participated in a series of activities[2] designed to elicit and form consensus around emerging design principles for online and blended teacher PD programs in K–12 STEM education (see *Figure 1, p. 3*). The resulting principles are organized and presented around three themes:

1. Motivating and Sustaining Engagement that Builds Knowledge and Advances Professional Goals
2. Creating Opportunities for Teachers to Collaborate as Learners
3. Supporting Reflection on Content and Practice

Participating awardees also described opportunities and challenges associated with each theme in online and blended settings. Finally, they highlighted opportunities for further research that could enhance the design principles presented below, inform the development of new principles, and address challenges that are common across projects.

As these projects and other research efforts continue to generate empirical evidence around design approaches — including the contexts in which and the audiences for whom they are effective, and their impacts on instruction and student learning — the design principles presented here are intended to serve as guidance for the ongoing and future work of (1) researchers and developers of teacher PD programs and (2) administrators and teacher leaders who plan, implement, and facilitate online offerings for PD programming in their schools and districts.

The emerging principles in this report were generated based on experience and initial evidence from across DRK–12 projects.

[2] See Appendix B.

Emerging Design Principles

I. Motivating and Sustaining Participant Engagement

- Encourage teachers to participate in decision-making about their learning.
- Provide support for online applications.
- Create mutual accountability structures among participants.
- Integrate face-to-face and/or synchronous, video-based meetings throughout PD programs.
- Use pre-established structures to maximize productivity during synchronous online sessions.

II. Creating Opportunities for Teachers to Collaborate as Learners

- Begin PD programs with face-to-face interactions.
- Facilitate connections between individuals.
- Structure online discussion to encourage collective participation.
- Leverage user-friendly platforms designed to support collaboration.

III. Supporting Reflection on Content and Practice

- Use artifacts that offer low-risk participation opportunities as the basis for early discussions on content and practice.
- Facilitate teachers' reflection on artifacts of practice that are both immediately practical and useful for deeper learning.
- Design tasks and prompts to encourage deep reflection and learning around artifacts.
- Schedule sessions to build in time for participants to apply ideas and reflect on their application.

Figure 1. Emerging Design Principles for Online and Blended Teacher Professional Development in K-12 STEM

I. Motivating and Sustaining Engagement that Builds Knowledge and Advances Professional Goals

People are wired to be learners, seeking out opportunities to gain knowledge and skills that are relevant to their work, play, or interests. In professional contexts, these learning opportunities are most effective when they take place over time, allowing for cumulative engagement with content, implementation of and reflection on new practices, and the sharing of knowledge and feedback with colleagues (Csikszentmihalyi & Csikszentmihalyi, 1988; Darling-Hammond, Hyler, & Gardner, 2017). Addressing the challenge of motivating and sustaining teacher engagement during professional development (PD) — whether it is face-to-face, wholly online, or a blended version of the two — involves creating conditions that stimulate and support, rather than prevent or weaken, teachers' natural affinities for learning in the service of strengthening their instructional practice. A number of scholars have identified core PD characteristics that support these affinities (Garet, Porter, Desimone, Birman, & Yoon, 2001; Heck, Banilower, Weiss, & Rosenberg, 2008; Lock, 2006; Neuman & Wright, 2010; Taylor, Roth, Wilson, Stuhlsatz, & Tipton, 2017; Wlodkowski, 2003). These characteristics include

- a focus on authentic content,
- opportunities for engaging in active learning,
- relevance to teachers' perceived needs,
- connections to practice, and
- coherence with respect to school and district priorities and initiatives.

Studies on PD vary widely in whether and how they discuss participant engagement, which we define here as active participation in PD activities and reflection on the implications of these activities for teaching and learning. While our review found few research efforts that focus specifically on promoting teacher engagement in online PD, the literature does include discussion of opportunities and challenges in motivating and sustaining engagement in online settings. Many of the principles of effective PD, regardless of the modality, pertain in online environments, and the challenges relate to implementing those principles effectively.

Opportunities and Challenges

Opportunities. A number of characteristics of online learning environments enable teachers to engage in professional learning in ways that are less feasible in face-to-face contexts. Anytime-access to resources and asynchronous activities allow teachers greater flexibility and control over the timing of their participation; teachers are better able to move at their own pace and manage the amount of work they do at one time (Fishman et al., 2013).

Online PD also has the potential to support contributions from teachers who might engage less frequently or differently in face-to-face contexts. For example, well-designed online features and tools (e.g., engaging prompts in a discussion thread) can support open discussion and the contribution of multiple voices to a rich dialogue. Integrating commonplace platforms (e.g., Google Hangouts, Facebook) within an online toolset can heighten these outcomes by providing a sense of familiarity to users. The ability to control the timing of their online participation, particularly in asynchronous settings, may also benefit those participants who are less comfortable speaking in face-to-face contexts or who want to take more time to reflect on their ideas before sharing (Swan, 2002). Online structures such as discussion forums, comment threads (in response to posted items), collaborative documents, and online journals or notebooks may allow such teachers to participate more fully in the PD. The online environment can also "democratize" participation by downplaying an individual's physical

cues related to gender, age, race, or disability that may affect others' responses to them (Swan, 2002).

Finally, online PD may offer teachers greater choice for customizing their professional learning programs, thus increasing their inclination to engage actively and productively with course content. For example, Brodesky and her colleagues describe a model for differentiated PD that enables teachers to tailor their PD experience at certain "choice points" to support individual needs and/or preferences (see *Example: Differentiated Professional Development*) (Brodesky, Fagan, Tobey, & Hirsch, 2016). Choice points offer a PD version of the "choose your own adventure" format popular among young readers: after core content has been addressed, teachers may select from among different options in order to expand and personalize their learning. The choice points themselves are based largely on formative data collected by the PD developers about the range of teachers' knowledge, experience, and interests.

Another kind of choice point relates to the modality through which teachers access information. Some teachers may prefer viewing videos as a means of acquiring information; some may be more comfortable with text-based resources; and others may appreciate the redundancy of information and refer to both. Brodesky and colleagues indicate that the privacy of the online environment often may be more conducive than in-person interaction to supporting the differentiation of teachers' PD experiences. For instance, a teacher in a face-to-face workshop may choose not to ask questions about the basic elements of the mathematics they teach if they sense that many of their colleagues are more comfortable with the subject, but may welcome the chance to work privately and at their own pace online. And although time constraints in face-to-face environments would likely limit the range of topics that a teacher could explore, in an online environment, they would have the discretion to work on additional activities that they may consider to be outside the bounds of the primary focus of the PD.

Challenges. The challenge of initiating and sustaining teacher engagement is not unique to the online context but can be exacerbated and take on new dimensions in online settings. For example, professional learning for mathematics and science teachers is typically designed to include collaboration and reflection on tasks that may be cognitively demanding for some or may challenge teachers' ideas about their instructional practice. It may be more difficult to sustain teacher participation in online PD experiences that take teachers out of their comfort zones and are perceived as risky. Teachers' motivation to fully engage can also be affected by the degree to which the learning environment is perceived as safe and supportive (Lock, 2006; Wlodkowski, 2003). The lack of physical (and, often, temporal) proximity among online learners diminishes access to nonverbal indicators of participant engagement for PD facilitators and participants alike. Fewer cues about teachers' connection to ideas under discussion, their sense of

Example: *Differentiated Professional Development (DPD)*

The DPD project offers a blended PD program for grades 4-7 mathematics teachers and special educators, with an emphasis on teaching students who are struggling in the areas of fractions, decimals, and positive/negative numbers. The program is designed to differentiate professional learning to address teachers' wide range of prior knowledge, experiences, and interests. The DPD approach has three main components: core activities that everyone does, choice points that offer different options, and self-reflection activities. For example, in a PD session focusing on students' difficulties with extending multiplication from whole numbers to fractions, teachers explore representing fraction multiplication with an area model (in the core activities). After their initial work with the model, teachers may choose from three possible subsequent activities (a choice point). Teachers relatively unfamiliar with using an area model in this context can continue to explore the model itself; those interested in using digital technology in their classrooms can explore the model through an applet; and those who want to extend their thinking about the model can try more challenging problems and work on creating some of their own. These choice points are provided online through interactive menus, and are also built into face-to-face PD sessions.

Learn more ▶ go.edc.org/dpd

comfort and safety while participating in activities, and their reactions to others' contributions can increase the challenges involved in promoting and sustaining productive learning environments for all. In addition, PD leaders and facilitators use discussion boards or other online tools without investing the resources and time required to develop activities and supports to engage teachers in the online environment (Schlager, Fusco, & Schank, 2002).

Technical demands may also affect ongoing participation. Online PD is often viewed as a simple, alternative mode of engagement for teachers in disparate locations, including those who may be geographically distant or isolated; however, the infrastructure needed to support online access is still limited in many areas. Although the country is making strides toward meeting goals for minimum connectivity in public schools, more than 19,000 schools still do not have the bandwidth to provide digital learning opportunities for their students — or to provide digital resources or access to their teachers while at work (EducationSuperHighway, 2017). Even with adequate infrastructure, online PD may fail to motivate or engage teachers who do not feel comfortable or skillful using technology. Another challenge to online PD, therefore, is to find technical support for those in need, and to differentiate resources and tasks for teachers with different levels of comfort and expertise with technology.

Emerging Design Principles

As DRK–12 projects develop, implement, and research online PD offerings, several design principles are emerging related to motivating and sustaining participant engagement.

Encourage teachers to participate in decision-making about their learning.

Provide opportunities for teachers to select topics, experiences, and resources that they believe will best address their needs. For example, use online breakout rooms to organize participants into smaller online groups in order to focus on different topics or tasks, offer choice points for activities that build on core experiences, or provide resources that are differentiated in terms of levels of difficulty or mode of presentation.

Provide support for online applications.

When possible, leverage ubiquitous and familiar platforms that demand little cognitive overhead from participants, and provide technical support for those unfamiliar with digital platforms. In blended programs, embed online tools and activities within face-to-face sessions so that participants have the opportunity to increase their comfort and skill with digital technologies when staff members are physically available to troubleshoot as needed. Building in time for teachers to familiarize themselves with platforms before they actually need to use them increases the likelihood that they can successfully undertake basic tasks such as logging in, uploading materials, and posting to discussion forums (see E*xample: PlantingScience: Digging Deeper*).

Example: *PlantingScience: Digging Deeper*

PlantingScience engages high school science teachers and scientists as collaborators in teaching and facilitating real-world science experiences for students. As part of its blended PD model, teachers and early-career scientists attend a five-day in-person workshop before participating in the *PlantingScience* online mentoring community with students throughout the fall semester. Teachers and scientists also participate in a series of webinars and online, forum-based reflection activities. Prior to the initial five-day workshop, participants complete an online "scavenger hunt" style activity to orient them to the program website, resources, and tools. During the in-person workshop, teachers interact with scientists using the website (sometimes from separate rooms) to model what their students will be doing during the fall. PD staff are available in-person during the workshop to provide technical support and guidance as needed.

Learn more ▶ go.edc.org/plantingscience

Create mutual accountability structures among participants.

Organizing subgroups or cohorts within a PD program can help support participant retention and engagement, especially if the groupings capitalize on existing social structures. In practice, this approach is often realized by creating multiple opportunities for participants to interact with each other in real time, share their experiences implementing common practices or materials, and provide feedback around common challenges. For example, projects have had success in pairing participants from different districts to serve as cross-district discussion buddies.

Integrate face-to-face and/or synchronous, video-based meetings throughout PD programs.

Consider adding face-to-face and/or synchronous online video-based meetings at regular intervals during the PD program to provide opportunities for participants to build and strengthen relationships with one another and share common work goals. Planning a face-to-face meeting toward the halfway point in the course can help teachers reconnect and reinvigorate the group. Synchronous, online meetings every six to eight weeks may also help support ongoing participation. For example, in DRK–12 projects, virtual meetings as short as 45–60 minutes and as long as two to three hours have been found to help sustain focus and commitment.

Use pre-established structures to maximize productivity during synchronous online sessions.

Although synchronous activities have the potential to promote engagement, they can be difficult to incorporate into PD programming and to schedule at times that work for all participants. As synchronous opportunities may be limited, make the most of these sessions through carefully planned discussions and activities. For example, begin with a sponge activity (i.e., an introductory activity that is relevant to the session while also serving to "soak" up extra time) as participants join. Design the session to accommodate one or two activities that allow participants to engage with each other around PD learning goals, and provide time for participants to reflect on and express takeaways at the end. Providing an agenda in advance and using a consistent format can also help participants know what to expect during these sessions.

II. Creating Opportunities for Teachers to Collaborate as Learners

Teachers' professional learning rarely occurs in isolation. Instead, teachers develop their professional practice within collaborative relationships or communities of practice (CoP) (Lave & Wenger, 1991; Putnam & Borko, 2000; Rogoff, 1994) in which they learn with, and from, their peers by sharing knowledge, perspectives, and practices; responding to one another's ideas; and working together on common tasks (Heck, Banilower, Weiss, & Rosenberg, 2008; Borko, 2004; Brisco & Peters, 1997; Curtis & Lawson, 2001; Darling-Hammond, Hyler, & Gardner, 2017; Desimone, 2011; Garet et al., 2001; Kirschner & Lai, 2007; Lewis, Perry, Friedkin, & Roth, 2012; Putnam & Borko, 2000). How such collaborative relationships are productively organized, nurtured, and sustained is a question for creators of both online and face-to-face PD programs (Bryk, 2009; Lewis, Perry, & Murata, 2006). Collaboration is often developed via a CoP in which teachers share their goals, practices, and resources with fellow teachers. While research has shown the CoP model to be effective at enabling teacher learning (Barab, Barnett, & Squire, 2002; Wenger, 1998), more research is needed to investigate its online implementation.

Opportunities and Challenges

Opportunities. By removing the need for learners to be physically present, online PD allows teachers to

collaborate over time and space in ways that are not possible in strictly face-to-face contexts. A Boston teacher can post a comment about an approach that they used in their classroom at the end of their school day and receive a message back the following morning from a colleague in Bakersfield, California, who tried the same approach. For asynchronous elements of online PD, work can extend beyond the temporal limits of the two- or three-hour blocks of time typically allocated to face-to-face meetings. Participants can continue to share their thoughts and work at times convenient to them and, similarly, others can build on the group's work at their convenience. Online and blended models can be particularly beneficial to teachers in rural schools and districts, providing opportunities that may not exist locally and therefore helping teachers form a broader professional community and base of support.

Online PD also has the potential to offer teachers exposure to a more heterogeneous group of fellow learners—teachers from different schools, districts, and states are likely to offer a wider variety of perspectives and approaches than is typically the case when participating in face-to-face PD in one's local area. The essentially unbounded capacity of web-based spaces offers the additional opportunity to grow learning communities that are far larger than is physically feasible, although there are challenges involved in facilitating learning in online communities of significant size (e.g., MOOCs). The ability to engage more learners offers greater opportunities for the spread of ideas ("social contagion") and the normalization of practices. Sharing reports of successful implementation of a practice by teachers from disparate school backgrounds helps establish that these practices are viable. In the same vein, teachers may be encouraged to try out new practices when they can access others' stories about positive student outcomes and the process of enacting new ideas.

Challenges. Many of the challenges in promoting online collaboration relate to finding effective ways to encourage interpersonal connections and group norms that support teachers' openness to new ideas and practices, some of which may unsettle their established approaches to their work and create some sense of uncertainty and vulnerability. Text-based communications lack the nuance of physical and vocal cues that help convey the underlying intent and meaning of messages, and may thus be more difficult to interpret. Miscommunication (or missed communication) may be harder to detect and repair in threaded, online conversations.

Particularly in asynchronous contexts, online discourse seems to require more active facilitator involvement in order to establish and encourage discussion, interaction, and community-building among PD participants. One reason for this challenge may be that tools for online discussion do not support the same ebb and flow of collaboration and conversation that is possible in face-to-face settings. For example, while asynchronous discussions do allow teachers to take time to reflect on and shape their ideas before sharing them; discussion threads that are lengthy and difficult to follow, or that include long expositions rather than efforts to engage in dialogue with others, tend to discourage collective knowledge-building. Without facilitation, either from course instructors or other colleagues, online discussions can turn unproductive.

In online environments, facilitators may also have access to fewer non-verbal cues about how participants respond to questions or prompts or how they engage with one another around common tasks. Even synchronous videoconferencing provides less information to the facilitator about how individuals and the group as a whole are processing the work. In taking the temperature of a group, the facilitator may also need to recalibrate expectations for the rhythm of collective work and discourse of online work. Haavind and Carter have suggested, for example, that "wait time" has a different metric in online contexts; while wait time in face-to-face environments may be a matter of minutes, it has a much longer half-life online, where participants may not respond to postings to questions or comments seeded by facilitators for a full day or longer (2011).

Some of the technical challenges that can limit teachers' ability and/or willingness to participate in online PD are

also likely to restrict teachers' ability to collaborate in the online realm. For example, many course features that can support shared learning and relationship building (e.g., synchronous videoconferencing) depend on participants' access to high-speed internet, which can be particularly problematic in locations with limited bandwidth. The lack of ability to communicate effectively with colleagues during video sessions can undermine participation in collaborative discourse and problem solving. A related challenge involves providing structures and identifying online tools that can facilitate online group work in real time (e.g., collective problem solving, analysis of student work, or viewing and discussing classroom video) (Francis-Poscente & Jacobsen, 2013).

Emerging Design Principles

The following design principles related to collaboration are emerging from researchers and teacher educators who are using online PD in their DRK–12 project work.

Begin PD programs with face-to-face interactions.

Among DRK–12 projects, blended models with initial face-to-face interactions appear to be the most common (or at least most often recommended) approach for developing relationships and establishing group expectations and cultural norms for working together. Connecting online and face-to-face interactions can mutually reinforce the development of relationships, understanding of practice, and building of capacity among teachers, since teachers can meet each other in a more intimate setting and then continue to learn from each other outside of physical constraints.

Facilitate connections between individuals.

In both blended and online-only models, PD providers can facilitate a sense of community and collaboration by identifying and leveraging connections among participants based on geographic location, grade level, discipline, shared challenges, or other salient areas for potential common interest and joint work (see E*xample: Teachers with GUTS*). Relationship-building and interactions do not need to be limited to a particular set of PD activities; by creating structures and processes for continued connection outside of specific PD assignments, PD providers support further relationship-building that can enhance teacher collaboration, learning, and practice in an ongoing way.

Example: *Teachers with GUTS*

Teachers with Guts engages middle school science teachers in up to 80 hours of PD over the course of a year through an intensive one-week summer workshop, webinars, practicum experience, facilitator support, and online PD network. The program supports teachers in using the *Project GUTS Computer Science in Science* curriculum and in developing instructional practices that engage students in computer modeling, simulation, and the powerful practice of computational thinking. The online PD network provides just-in-time resources and support as well as opportunities for participants to connect with one another. Teachers are invited to create online profiles, sharing information about themselves as well as links to resources and discussions to which they have contributed. Participants can also categorize themselves as interested in learning about a certain topic or being able to mentor another in their learning of a topic. By making such information searchable within the community, participants motivated to make connections with other teachers can easily do so.

Learn more ▶ go.edc.org/Tguts

Structure online discussion to encourage collective participation.

Teachers should be able to build easily on others' ideas regarding substantive issues of content and practice. Achieving rich discussions in which teachers can reflect and comment on others' ideas requires careful design of discussion prompts, questioning strategies, and thoughtful instructor participation at

key points (Jarosewich et al., 2010). For example, creating initial and follow-up prompts allows for a range of responses so participants can more easily recognize opportunities to contribute. Particularly in asynchronous contexts, it is important that the online interface be intuitive in terms of discussion organization and navigation.

Leverage user-friendly platforms designed to support collaboration.

DRK–12 projects have had success conducting online video-based meetings using platforms such as Zoom, Google Hangouts, or Adobe Connect. These platforms have the capacity to divide participants into smaller break-out groups, much as teachers do when they work in small groups together on a task. Synchronous, online meetings using video-based platforms allow participants to see each other and to collaborate on common tasks in real time (see *Example: Visual Access to Mathematics*).

PD participants will be able to participate more fully in collaborative work when the digital technologies they must access demand little cognitive overhead, thereby enabling teachers to focus their energy and attention on the cognitive demands of the work itself. Projects have also found it useful to use digital applications, such as Explain Everything (an online interactive whiteboard), to produce media-rich screencasts of student or participant work that can be used to engage in deep and rich discussions. Provide technical support for those whose participation is limited by lack of ease with online modes of communication.

Example: *Visual Access to Mathematics*

VAM is a year-long, blended PD course for educators of middle-grades mathematics students who are English learners. The course focuses on the use of mathematical visual representations and language support strategies to promote student understanding of rational number concepts. The course begins with a face-to-face summer institute and continues throughout the school year with 8 two-week online sessions and 2 one-day face-to-face workshops scheduled halfway through the year and at the conclusion of the course. The online sessions feature both asynchronous online interactions (e.g., mathematics tasks explorations, analysis of student work, and reflection on instruction in discussion boards) as well as periodic opportunities for synchronous, small-group discussion and sharing through videoconferencing and interactive whiteboards. The face-to-face and synchronous virtual sessions allow participants to discuss and collaborate on tasks in real time and help maintain interest and engagement throughout the duration of the course. VAM leverages a variety of platforms to support collaboration, including Moodle for hosting resources and links to activities; Zoom for videoconferencing and screensharing; Explain Everything for creating artifacts of mathematical work and communication; and Seesaw for creating digital portfolios of student and teacher work.

Learn more ▶ go.edc.org/vam

III. Supporting Reflection on Content and Practice

All modalities of PD (online, face-to-face, and blended) support teacher learning when (1) teachers rigorously engage with and reflect on disciplinary content (Roskos, Jarosewich, Lenhart, & Collins, 2007) and (2) teachers reflect on and analyze instructional practice and artifacts of that practice (Borko, Jacobs, Eiteljorg, & Pittman, 2008; Brophy, 2003; Desimone, 2009; Polly & Hannafin, 2010). These emphases align well with the characteristics of PD conducive to engagement described on pg 4: authentic content, active learning, and connections to practice (Darling-Hammond et al., 2009; Desimone, 2009). In recent decades, a growing number of education researchers have examined the role of metacognition in learning across all settings and age groups. Metacognition involves monitoring one's own understanding and assimilation of new knowledge as part of the learning process; in addressing the concept as it applies to teaching, Bransford and colleagues state that "teaching practices congruent with a metacognitive approach to learning include those that focus on sense-making, self-assessment, and reflection on what worked and what needs improving." (National Research Council, 2000, p. 12).

In both online and face-to-face settings, opportunities to engage with challenging disciplinary content and engage in artifact-based PD have shown tremendous promise for mathematics (Borko et al., 2008; Goldsmith & Seago, 2011; Santagata, 2009; Star & Strickland, 2008; van Es & Sherin, 2008) and science teachers (Hammer & van Zee, 2006; Levin & Richards, 2011; Roth et al., 2011; Taylor et al., 2017). Resources and strategies to support teachers' reflection on and development of subject matter knowledge can include interactive learning experiences, animations, readings, and analysis of student work or discourse. Artifacts can include videos, student assignments, lesson plans, and other work samples from a teacher's own classroom or from others' classrooms.

Although artifacts such as videos are often used as a basis for examining instructional practice, Roth and colleagues found that it is also possible to use teachers' reflections on classroom video as means of enhancing teacher content knowledge through examination of student thinking (2011). A skilled leader can ask teachers to discuss student thinking apparent in a video and consider any productive beginnings or potential misconceptions students may have. In a face-to-face setting, the discussion can (and often does) turn to teachers' own ideas about the concepts (Roth et al., 2011). Incorporating videos and artifacts specific to a teacher's own classroom can enhance motivation and resonance (i.e., a teacher's ability to make connections to their own practice) (Seidel, Stürmer, Blomberg, Kobarg, & Schwindt, 2011), whereas videos of others can potentially enhance teachers' abilities to reflect critically on events (Seidel et al., 2011).

Opportunities and Challenges

Opportunities. To support deep content learning, online teacher PD must integrate opportunities for knowledge construction that can successfully guide teachers toward improved understanding, often *without* the support of immediate instructor–teacher discourse. Interactive learning experiences and simulations offer one option for rigorously engaging teachers with content. Rather than simply providing ideas for teachers to consume, interactive learning components allow teachers to explore relationships among variables, make changes to a system, observe how changes to the system affect outputs, and construct an understanding of relationships from the data they collect from the experience (see *Example: Energy: A Multidisciplinary Approach for Teachers*). Follow-up questions can provide further guidance for how teachers might focus their thinking about the interactive experiences and the associated concepts. With sufficient resources, an online PD program could also incorporate interactives that use artificial intelligence (AI) to automatically provide individualized feedback to teachers as they construct understanding of key concepts; however, developing high-level interactive learning experiences is both time consuming and expensive. The plethora of simple didactic online

Example: *Energy: A Multidisciplinary Approach for Teachers (EMAT)*

EMAT is an online course that helps preservice and inservice teachers frame complex energy concepts in a way that will resonate with high school students. Through a variety of activities, teacher participants improve their own content understandings and learn to reveal, support, and challenge student thinking about energy concepts (e.g., energy transfer). Asynchronous activities include analysis of classroom video as well as opportunities for independent exploration of complex science content through interactive learning experiences and animations. For example, in an interactive simulation of wind power generation, participants can manipulate variables including wind velocity, tower height, and blade length to visualize and maximize the number of homes powered by wind turbines. The interactive experience allows participants to connect wind power generation ideas to fundamental concepts surrounding efficiency of energy transfer. EMAT animations are designed to make complex, dynamic processes clearer. For example, through animation, participants can visualize how nuclear power plants harness energy from fission to generate electrical energy. In addition to asynchronous activities, two-hour, synchronous small-group discussions are dispersed throughout the course and provide an opportunity for participants to consider instruction through student thinking and science content storyline lenses.

Learn more ▶ go.edc.org/emat

PD offerings may reflect the high cost of incorporating more constructivist interactive approaches.

In other ways, online PD need not differ from face-to-face PD regarding rigorous engagement with content and artifacts of practice. Technologies have been advancing rapidly, allowing for videoconferencing as well as shared screens and whiteboards. Non-verbal and non-textual forms of communication (i.e., ideas best expressed with symbols or drawings) that are natural in a face-to-face setting can be easily incorporated into online PD. Learning management systems accommodate a variety of digital media, including video, and documents such as lesson plans can be uploaded or shared in real time.

Online environments are often media friendly and can provide natural contexts for examining digital artifacts such as video. Because video can easily be incorporated into an online environment for personal, asynchronous viewing, and because discussion boards allow teachers to construct thoughtful responses to prompts, the use of classroom video to support teachers' own conceptual understandings and/or improved instructional practice is likely within reach for many PD designs.

Challenges. Rigorously engaging teachers in content and promoting reflection during online PD poses several challenges, particularly in asynchronous contexts. In face-to-face PD, a facilitator can interact flexibly with teachers, asking them questions in real time and pressing them to construct understandings in relation to shared experiences. However, in asynchronous environments, real-time instructor/teacher exchanges are absent. Even in synchronous online contexts, it can be difficult to support teachers in constructing knowledge using discursive moves. Rigorous engagement with subject matter content—especially if working, thinking, talking, and listening in ways that are unfamiliar or new—can be challenging for teachers. This is often exacerbated in online environments where switching the "presenter" (i.e. the person speaking) can take time and slow down the discussion in problematic ways; where writing and drawing can be difficult and awkward; when local distractions or transmission/reception distortions can make it challenging to consistently follow and participate in the discussion; and when it is easy to simply not respond to prompts that are addressed to a group.

A challenge for the online PD environment is to shape the depth and quality of the conversation, particularly in asynchronous environments (Jarosewich et al., 2010). As is the case with face-to-face PD, simply asking teachers in online settings to look at artifacts of practice will not necessarily enhance teacher learning (Atkins, 1998; Friel & Carboni, 2000; Krajcik et al., 1996; Rosaen, Schram, & Herbel-Eisenmann, 2002). Video-based PD often includes video analysis tools and protocols as well as explicit instruction for using the tools; however, many video analysis tools assume that a transcript exists for the classroom video under analysis. Designers in online environments must, therefore, identify and implement strategies to ensure that video analysis tools, instruction in their use, and even classroom transcripts are fully integrated into the online PD experience, along with the artifacts themselves. Effective learning from videos also requires facilitation of ideas and reflection, which typically takes place in in-person settings (Miller & Zhou, 2007; van Es, Tunney, Goldsmith, & Seago, 2014). Thus, facilitators in asynchronous environments need to be particularly creative in encouraging participants to reflect on their and others' practice.

The challenges associated with incorporating classroom video into a rich online PD experience are not insurmountable. Designers can create animations showcasing the use of video analysis tools; transcripts can be linked to video either as a PDF or through robust video coding software tools such as VideoAnt; and video coding protocols can be converted to online, digital forms (such as Google Forms) or integrated into discussion boards. However, the logistical challenges associated with using video online grow exponentially if a PD leader wants teachers to reflect on their own classroom video and those videos require transcripts for analysis. Often there is not sufficient time for teachers to capture classroom video and obtain transcriptions of it within the timeframe

of a PD experience. Ready-made classroom videos of teachers not participating in the PD can alleviate the timing challenge but have their own drawbacks (Seidel et al., 2011). Depending on the type of analysis, use of video annotation software (e.g., Edthena and VideoAnt) can obviate the need for transcripts.

Another important challenge in video-based online PD relates to the level of trust necessary for productive conversations between teacher participants about video artifacts. Teachers generally require a high level of trust to share video of themselves with others and to critique the video of a peer in a constructive manner. Face-to-face PD offers teachers the ability to develop and build community and trust over time, whereas community and trust in online PD environments can be more difficult to establish (Barab, 2003; Schlager et al., 2002).

Emerging Design Principles

DRK–12 projects have identified several emerging principles related to supporting reflection on content and artifacts of practice. These principles are also relevant in face-to-face PD contexts, but they are highlighted here because their implementation in online environments involves unique considerations and/or strategies.

Use artifacts that offer low-risk participation opportunities as the basis for early discussions on content and practice.

Establishing collaborative and trusting communities in online professional learning environments is a critical and complex task (Schlager et al., 2002). It is, therefore, especially important that during (and in service of) their development, PD designers consider structuring reflections and discussions around more neutral artifacts (see *Example: Learning Labs*). A potentially good entry point is to share examples of students' written work; a somewhat riskier participation opportunity is for teachers to comment on the video of a teacher who is not part of the PD experience. Although reflecting on one's own video can be highly motivating, teachers can have difficulty analyzing critical events in their own classrooms. Discussions around teaching moves, orchestrating discourse, and questioning strategies in teachers' own classrooms are high-risk participation opportunities for teachers. Regardless of *what* is discussed, it is important establish good norms and expectations for discussing videos and other artifacts of practice. Developing a safe and productive environment for professional discourse can (and should) take place from the beginning, even when using neutral artifacts. The conversation around neutral artifacts should look much as it would if the student or teacher who produced the artifact or who appears in the video was sitting at the table: focused on supporting learning—thoughtful, growth-oriented, respectful, and acutely aware of how little is known from the small glimpse offered by the video/artifact.

Example: *Learning Labs*

The *Learning Labs* project offers a series of online-only and blended PD experiences focused on facilitating disciplinary practices of modeling and argumentation in K-2 mathematics and science classes. During each Lab (10 weeks in duration), participating teachers collaborate in a variety of opportunities to learn in, from, and for instructional practice. These include, but are not limited to, engaging in modeling or argumentation as adult learners, analyzing video of primary classrooms engaging in disciplinary practices, and sharing examples and reflections from their own instructional practice as they try out common activities. To help support participants in making their practice public in online spaces, *Learning Labs* intentionally integrate initial activities to facilitate community building and sharing across classrooms. For instance, during the first week of a Lab, teachers are asked to film a short (~2 minutes or less) tour of their classroom and highlight any instructional ideas they are working on or about which they are especially excited. This activity begins the work of opening classroom doors and invites teachers to see each other as knowledgeable colleagues. Teachers are then asked to respond to each other's videos the following week by highlighting interesting noticings, new ideas, connections, and/or questions — launching initial conversations about instruction in a low-stakes way.

Learn more ▶ go.edc.org/learninglabs

Facilitate teachers' reflection on artifacts of practice that are both immediately practical and useful for deeper learning.

Specifically, PD leaders should consider the purpose of the reflection opportunity, the likelihood that the artifacts will promote rich discussion, and the logistics of their collection and sharing (Bates, Phalen, & Moran, 2016). As much as possible, these artifacts should be easy to collect in the moment or in the course of day-to-day teaching yet should also be rich enough to support later reflection, analysis, and discussion. If the primary goal is to for teachers to critically consider their own practice, teachers' own videos are ideal. However, editing and/or uploading videos may be time consuming and require additional technical skills. In addition, if teachers are to reflect on key strategies that are difficult to implement, novice videos may not be the best choice.

Design tasks and prompts to encourage deep reflection and learning around artifacts.

Eliciting substantive reflection and supporting rich discussion around artifacts can be challenging in online environments—particularly asynchronous environments—but student-focused (compared to teacher-focused) video clips and targeted (compared to open-ended) prompts may lead to more reflective and analytic responses (see Example: Everyday Mathematics VLC). However, one size does not fit all in discussion prompts, particularly in online environments (Jarosewich et al, 2010), and the design of the prompts should carefully match the goals of the discussion.

Schedule sessions to build in time for participants to apply ideas and reflect on their application.

For example, scheduling eight sessions over the course of the year will allow teachers sufficient opportunities to apply new methods and approaches in their classrooms, collect artifacts from their implementation, reflect on the results, and share them with colleagues. The timing and nature of PD tasks should also be informed by the competing demands on teachers' time, where task loads should reflect the realities of teacher schedules.

Example: *Everyday Mathematics Virtual Learning Community (VLC)*

The *Everyday Mathematics* VLC, which currently has close to 50,000 members, offers instructional resources, classroom videos, PD guides, and discussion boards for elementary mathematics teachers. Although the site is designed to support any interested teacher, its resources and activities are particularly relevant to those implementing the *Everyday Mathematics* curriculum. VLC members have on-demand access to a range of materials to support professional learning, and can participate in asynchronous viewing and commenting on lesson videos and/or join a variety of user groups to discuss questions about the *Everyday Mathematics* curriculum, troubleshoot pedagogical and technology issues, and further collaborate around problems of practice. In efforts to understand how to support teacher professional learning asynchronously, two studies investigated teachers' reflective commentary, which has been found to be related to positive student outcomes. Bates et al. (2016) found that the design of video clips to include mostly students (with teachers absent or acting primarily as facilitators of student conversation) seemed to provoke more reflective commentary. Beilstein, Perry, and Bates (2017) examined how directed prompts could support deep reflection. They found that teachers' responses were malleable and sensitive to prompt types. For example, commentary was most analytical when prompts focused on the teacher portrayed in the video. Participants were less analytical but provided rich descriptions of video content when prompted to focus on student thinking.

Learn more ▶ go.edc.org/vlc

Areas of Needed Research

In online spaces, PD developers have the opportunity to increase access to and potentially transform high-quality professional learning experiences for teachers. They also face the challenge of creating structures, expectations, and learning environments that promote engagement, collaboration, and reflection across distance and time, with the ultimate goal of authentic, vibrant, and substantive online discourse that supports collective meaning-making and deep learning. While a growing body of research supports the potential for high-quality online professional learning, syntheses of research in this domain highlight needs and opportunities for future research that

- targets specific program features or combinations of features and their connections to teacher learning;
- examines impacts on teacher practice and student learning; and
- invokes a range of formative and summative methodologies (Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2009; National Academies of Sciences, Engineering, and Medicine, 2015).

Projects in the DR K–12 portfolio are actively contributing to this agenda as well as identifying or underscoring opportunities for further research to advance it. Through CADRE's *Survey and Forum on Emerging Design Principles for Online & Blended Teacher Professional Development*, awardees identified key questions related to motivating and sustaining engagement, promoting collaboration, and supporting reflection on content and practice in online and blended PD settings.

I. Motivating and Sustaining Engagement That Builds Knowledge and Advances Professional Goals

- What are the comparative merits of different online PD models as they relate to successful engagement of teachers?
- What patterns of engagement in online PD environments are associated with positive impacts on teacher practice and/or student learning?

II. Creating Opportunities for Teachers to Collaborate as Learners

- How does online collaboration differ from in-person collaboration?
- What aspects of initial face-to-face experiences contribute to improved collaboration in online environments?
- What are critical features of successful asynchronous discussions in which participants build on each other's contributions in an authentic way? What kind of front-end work is needed to ensure their success?
- What kinds of facilitation knowledge and/or strategies are needed to support participant ownership of continued collective work in online environments? Do synchronous contexts call on different facilitation knowledge and/or strategies than asynchronous contexts?
- What are principles for designing productive tasks and agendas for asynchronous and synchronous collaborative work?

III. Supporting Reflection on Content and Practice

- What types of prompts and feedback patterns are most effective in encouraging nuanced reflections on practice through asynchronous interactions? Are they different from those that encourage reflection on content?
- What types of prompts and feedback patterns are most effective in encouraging nuanced reflections on and discussion of content and practice during synchronous interactions? Do they vary based on the mode of synchronous discussion (e.g., videoconferencing, audioconferencing, or text-based discourse such as chat)?

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Appendix A: Online & Blended Professional Development Projects in DRK–12

In October 2016, the following projects were identified as having a potential focus on online or blended PD based on the information provided in their abstract. Although many other projects featured online resources and/or supports for teachers, CADRE did not include those whose online activities were ancillary to the project's research and development program. Links to each project's profile on cadrek12.org, and when known, links to the project's public website are provided.

** Project participated in the Forum on Emerging Design Principles for Online and Blended Professional Development and/or the subsequent production of this report.*

Building Capacity for Science Standards Through Networked Improvement Communities (NSF #1315995)
PI: Jessica Thompson
go.edc.org/cadre-nics

CAREER: Making Science Visible: Using Visualization Technology to Support Linguistically Diverse Middle School Students' Learning in Physical and Life Sciences (NSF #1552114)
PI: Kelly Ryoo
go.edc.org/cadre-makingscience

CodeR4STATS - Code R for AP Statistics (NSF #1418163)
PI: Brian Gravel
go.edc.org/cadre-codestats

Computer-Supported Math Discourse among Teachers and Students (Collaborative Research: Powell, Weimar) (NSF #1118888, 1743611)
PIs: Arthur Powell, Stephen Weimar
vmt.mathforum.org | go.edc.org/cadre-powell | go.edc.org/cadre-weimar

Developing a Discourse Observation Tool and Online Professional Development to Promote Science, Oral Language and Literacy Development from the Start of School (NSF #1620580)*
PI: Tanya Wright
go.edc.org/cadre-devdiscourse

Developing Teaching Expertise in K-5 Mathematics (NSF #1118745)*
PI: Tim Boerst
umich.edu/~devteam | go.edc.org/cadre-devteaching

Differentiated Professional Development: Building Mathematics Knowledge for Teaching Struggling Learners*[3]
PI: Amy Brodesky
edc.org/accessmath | go.edc.org/cadre-differentiatedpd

Energy: A Multidisciplinary Approach for Teachers (EMAT) Designing and Studying a Multidisciplinary, Online Course for High School Teachers (NSF #1118643)*
PI: Susan Kowalski
bscs.org/emat | go.edc.org/cadre-emat

Enhancing Teaching and Learning with Social Media: Supporting Teacher Professional Learning and Student Scientific Argumentation (NSF #1316799)*
PI: James Ellis
go.edc.org/cadre-enhanceteach

Facilitating Teachers' and Young Children's Science Learning Through Iterative Cycles of Teacher Professional Development (NSF #1621400)
PI: Eleanor Armour-Thomas
go.edc.org/cadre-sciencelearning

[3] This project was excluded from the 26 online and blended PD projects identified in Fall 2016, as it was no longer active. However, the PI is involved in active DRK–12 projects related to online and blended PD and drew on experience and results from the Differentiated Professional Development project in her contributions to this report.

Focus on Energy: Preparing Elementary Teachers to Meet the NGSS Challenge (Collaborative Research: Lacy, Seeley) (NSF #1418052, 1418211)
PIs: Sara Lacy, Lane Seeley
go.edc.org/cadre-lacy | go.edc.org/cadre-seeley

InquirySpace 2: Broadening Access to Integrated Science Practices (NSF #1621301)*
PI: Chad Dorsey
tinyurl.com/inquiryspace | go.edc.org/cadre-inquiryspace

Learning Labs: Using Videos, Exemplary STEM Instruction and Online Teacher Collaboration to Enhance K-2 Mathematics and Science Practice and Classroom Discourse (NSF #1417757)*
PI: Paul Teske
tinyurl.com/lrninglabs | go.edc.org/learninglabs

Math Snacks Early Algebra: Using Games and Inquiry to Help Students Transition from Number to Variable (NSF #1503507)
PI: Karin Wiburg
mathsnacks.org | go.edc.org/cadre-mathsnacks

Modest Supports for Sustaining Professional Development Outcomes over the Long-Term
PI: Cathy Ringstaff
go.edc.org/cadre-sustainingpd

Organizing to Learn Practice: Teacher Learning in Classroom-Focused Professional Development (NSF #1621104)
PI: Meghan Shaughnessy
go.edc.org/cadre-learnpractice

PlantingScience: Digging Deeper Together - A Model for Collaborative Teacher/Scientist Professional Development (NSF #1502892)*
PI: Catrina Adams
bscs.org/diggingdeeper | go.edc.org/cadre-plantingscience

Proportions Playground: A Dynamic World to Support Teachers' Proportional Reasoning (NSF #1621290)
PI: Chandra Orrill
go.edc.org/cadre-playground

Supporting Chemistry Teachers to Assess and Foster Chemical Thinking (NSF #1621228)
PI: Hannah Sevian
go.edc.org/cadre-supportchemistry

Supporting Large Scale Change in Science Education: Understanding Professional Development and Adoption Variation Related to the Revised Advanced Placement Curriculum (PD-RAP) (NSF #1221861)
PI: Arthur Eisenkraft
go.edc.org/cadre-pdrap

Supporting the Emergence of a Professional Teaching Community Through Collective Knowledge-Building in Assessment and Feedback of Mathematical Thinking (Collaborative Research: Brandt, Silverman) (NSF #1221351, 1222355)
PI: Carol Brandt, Jason Silverman
mathforum.org/encompass | go.edc.org/cadre-brandt | go.edc.org/cadre-silverman

Synchronous Online Professional Learning Experiences for Middle Grades Mathematics Teachers in Rural Contexts (NSF #1620911)
PI: Jeffrey Choppin
go.edc.org/cadre-synchonline

Systemic Transformation of Inquiry Learning Environments for STEM (STILE 2.0) (NSF #1621387)
PI: Ellen Meier
go.edc.org/cadre-stile

Teachers with GUTS: Developing Teachers as Computational Thinkers Through Supported Authentic Experiences in Computing Modeling and Simulation (NSF #1503383)*
PI: Eric Klopfer
teacherswithguts.org | go.edc.org/cadre-guts

Three-Dimensional Teaching and Learning: Rebuilding and Researching an Online Middle School Curriculum (NSF #1502571)*
PI: Susan Kowalski
go.edc.org/cadre-3d

Understanding and Improving Learning from Online Mathematics Classroom Videos (NSF #1621253)*
PI: Michelle Perry
go.edc.org/cadre-mathvideos

Visual Access to Mathematics: Professional Development for Teachers of English Learners (NSF #1503057)*
PI: Mark Driscoll
tinyurl.com/visualaccess | go.edc.org/cadre-vam

Appendix B: Methods

Survey on Emerging Design Principles for Online and Blended Teacher Professional Development

In February 2017, CADRE developed and administered a survey for awardees on 26 active DRK–12 projects identified as having a potential focus on online and blended teacher professional development. In addition to collecting basic information about projects' PD model (e.g., teacher learning goals, research questions related to the PD activities), survey items were designed to elicit:

- *existing design principles* underlying online projects' PD models;
- *emerging design principles* that reflect new approaches and evidence being generated in the surveyed projects; and
- *design principles* needed to address persistent challenge areas identified by surveyed projects.

Representatives from 10 projects completed the survey. CADRE analyzed survey responses to identify common themes across projects.

Survey Participants: Catrina Adams, Amelia Gotwals, Irene Lee, Johannah Nikula, Susan Kowalski, Jennifer Richards, Amber Rowland, Kara Suzuka, Robert Tinker, Tanya Wright

Forum on Emerging Design Principles for Online and Blended Teacher Professional Development Programs

Following survey administration and analysis, CADRE organized a synchronous, virtual forum to further refine the existing, emerging, and needed design principles articulated in the survey. CADRE recruited two PI facilitators to help consider the implications of the survey results, develop an agenda for a virtual forum, and facilitate forum discussions around design principles emerging from participants' collective work. The resulting agenda aimed to engage forum participants around two guiding questions.

1. What PD approaches accommodate different users and contexts?
2. How do we promote and maintain active engagement of participants through online interactions?

On March 13, 2017, 11 awardees, CADRE staff, and CADRE's evaluator participated in the two-hour virtual *Forum on Emerging Design Principles for Online and Blended Teacher Professional Development Programs*. After PI facilitators offered their perspectives on the forum topic and guiding questions, participants shared their reflections on themes from the survey results and discussed the guiding questions in small breakout groups. CADRE staff documented full-group and breakout conversations, and facilitated a discussion of key ideas and possible next steps. A primary outcome of the forum was the decision to create a written product summarizing emerging design principles for online and blended teacher PD based on research and development in DRK–12.

Forum Participants: Pam Buffington (facilitator), Chad Dorsey (facilitator), Meg Bates, Amy Busey, Jodi Creasap Gee, Lynn Goldsmith, Genevieve Henricks, Susan Kowalski, Catherine McCulloch, Cheryl Moran, Michelle Perry, Jennifer Richards, Derek Riley, Amber Rowland, Kersti Tyson

Report Development

CADRE produced a draft outline for a written product and invited comments and suggestions from awardees who had participated in either the survey or forum. After revising the outline based on feedback, CADRE recruited awardees to engage as lead writers, based on their expertise and project alignment with the outlined content. CADRE also recruited reviewers to provide consultation and feedback at multiple stages of the product's development. CADRE staff integrated section drafts produced by lead writers, provided an introduction with information about online and blended PD in DRK–12, and produced the final product for dissemination.

Lead Writers: Meg Bates, Shereen Beilstein, Amy Busey, Lynn Goldsmith, Susan Kowalski, Michelle Perry

Reviewers: Catrina Adams, Amy Brodesky, Chad Dorsey, Amelia Gotwals, Irene Lee, Jennifer Richards, Amber Rowland, Kara Suzuka