

Encouraging collaboration and building Community in Online Asynchronous Professional Development: designing for social capital

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Abstract

This research investigates a design and development approach to improving science teachers' access to effective professional development (PD) in a fully online, asynchronous environment. Working with a small number of teachers, this study explores how a design combining social capital mechanisms with essential teacher learning and PD characteristics supported teachers' abilities to participate in the online course and collaboratively build knowledge. Teachers' perceptions of their experiences both in surveys and interviews demonstrated high satisfaction with the quality and usability of the PD, including positive beliefs related to the social capital elements of tie quality, depth of interaction, and access to expertise. Further transactivity analyses of their interactions in course discussions showed higher levels of collaborative discourse resulting from prompts that specifically targeted the exchange of information over those that asked teachers to reflect about their content understanding or their classroom practice. Implications for this design for asynchronous online PD approaches to reach more teachers are discussed.

Keywords Social Capital · Online Asynchronous Learning · Teacher Professional Development · Transactivity

Global shifts in emphases in K–12 science education toward deeper understanding and greater application and utility of scientific knowledge and skills (e.g., European Commission 2015; National Research Council 2012) have created a steep learning curve for teachers. As a result, improving access to effective PD for all science teachers has been signaled as an immediate

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imperative (Wilson 2013). From 2010 to 2014, our team aimed at addressing this demand by developing and delivering face-to-face PD using computer-supported complex systems biology curriculum and instruction. Built on characteristics of effective PD for science teachers documented in various articles (e.g., Desimone 2009; Gerard et al. 2011), this work included providing hands-on teacher training, aligning PD with teaching contexts, exposing teachers to real-world scientific practices, and working with teachers as collaborators. Findings from several of our studies (e.g., Yoon et al. 2016, 2017a) have revealed high teacher satisfaction, high curricular utility, and increased student participation and learning outcomes. Importantly, strategic efforts to build teachers' social capital (e.g., relationships for access to external resources) in addition to building their human capital (e.g., individual knowledge and skills) improved their teaching from one year to the next (Yoon 2018). Teachers built on one another's knowledge, using each other as resources, and they specifically referenced these peer relationships as reasons for their increased confidence in the delivery of project activities.

The success of this project encouraged us to consider how to scale this work to reach more teachers. Although aspects of effective PD are well-defined within the PD literature, recent reports indicate that practitioners still face a persistent lack of access to it resulting from time and space issues related to scale. Merritt (2016) noted that among the highest concerns articulated by teachers for improving practice is the need for more and flexible time to access and process new information. Furthermore, Peltola et al. (2017) highlighted a dearth of access to professional peers and geographic isolation for teachers. This report and others indicated that online PD has the potential to supplement local, in-person experiences, where anywhere, anytime access to resources can potentially mitigate time constraints. Previous research has further suggested that these online PD experiences can produce comparable outcomes to face-to-face PD as measured by classroom behaviors and student outcomes (Fishman et al. 2013; Webb et al. 2017). However, the literature notes that the added affordances of online PD may be accompanied by other issues related to online interaction that potentially challenge the ability to connect with peers in deep and meaningful ways (Kop 2011). For example, collaboration among participants and social interaction that builds knowledge within communities are two conditions that encourage engagement but are not well supported technologically in online courses (Booth 2012; Kop 2011). Dede et al. (2009) suggested that more research is needed to capitalize on the unique affordances of online delivery platforms.

Additionally, asynchronicity, which can allow participants to access the PD anytime, is a feature that can potentially ameliorate the previously cited issues of the lack of flexible time and geographic isolation (Meritt 2016; Peltola et al. 2017); however, asynchronicity provides its own challenges to collective knowledge building and collaboration in an online space (e.g., Alterman and Harsch 2017). Difficulty collaborating and interacting can lead to dissatisfaction among online learners. In a review of asynchronous online learning communities, Yuan and Kim (2014) found that unfulfilled expectations for interaction and feelings of isolation can be common causes of drop out. Other research has identified a notable participation gap that continues to exist in such online spaces that may impact rates of participation, cognitive engagement, and cooperation (Chen and Huang 2019; Peterson et al. 2018). However, these studies did not examine PD specifically, and the application of this research to PD for teachers is nearly nonexistent. Despite these potential challenges, many studies highlight the promise of online PD in terms of participation outcomes for teachers. For example, in a national survey, Parsons et al. (2019) reported that 83.8% of teachers surveyed found online PD to be moderately to extremely beneficial. And of those teachers, 90% said that the ability to access

it anytime was very or extremely important. This suggests that asynchronous environments are highly valued. Likewise, in one of the purely asynchronous studies that does exist on teachers, An (2018) found a positive shift in participants' attitudes and an increase in self-efficacy. Thus, we think that solving the issues of collaboration and interactivity in asynchronous PD is worthy of continued research.

In the research reported here, we investigate how online PD can support science teachers' professional growth by encouraging development of social capital. We use transactivity analysis to provide a direct, quantifiable measure of the depth of social interaction among participants, while also providing insights into the other aspects of social capital discussed below. Teasley (1997) was one of the first studies that measured transactivity to examine how much information is shared and built on between peers in a collaborative learning context. In the ensuing years, transactivity analyses have been used to evaluate the success of computer-supported environments specifically constructed to scaffold collaborative knowledge building and reasoning (Gweon et al. 2013; Vogel et al. 2016). We believe that the results of our own analysis provide insights into the development of social capital among the participants in our PD.

Following our previous research, we wanted to investigate the application of an online social capital design, asking the following research question: To what extent can a PD course that is constructed through a social capital design and run asynchronously online deliver effective PD? Thus, our research goals are twofold: (a) to illustrate design features of the online PD and (b) to investigate teacher collaboration and perceptions of social capital given this design context. We probed the experiences of eight high school biology teachers who participated in a 6-week course delivered on the edX platform. We analyzed their impressions through targeted interview questions and more objective transactivity analyses of their interactions in discussion forum activities to understand levels of knowledge-building and social-capital development.

Theoretical considerations

In this section we outline in more detail two areas of research that inform our PD design. These include conceptualizations of PD quality in relation to teacher learning and designs for online collaboration; and designing to build teachers' social capital. We also discuss the notion of transactivity that constitutes an important measure of community building used in our methodology.

PD quality, teacher learning, and designs for online collaboration

The educational need to improve PD encompasses a number of issues, including utility in real school contexts, delivery quality, and lack of customization to teacher needs (Hill 2009, 2015; Hodkinson and Hodkinson 2005; TNTP 2015). Constructing effective PD opportunities is further complicated by what we know about how teachers learn. We know that optimal learning starts with teachers as knowers and agents of change, where social relationships are fostered for peer-to-peer support and where the examination of subject-matter pedagogy involves active sense making and problem solving (Cochran-Smith and Lytle 1999; Hatch et al. 2006; Lieberman and Mace 2010; Moon et al. 2014).

There is already research that can inform us on strategies for building networked teacher communities that are focused on sensemaking anchored in classroom practice and that position the teacher as the agent of change. For example, Lieberman and Mace (2010) and Hatch et al. (2006) discussed the importance of making practice public in online professional communities through multimedia tools that allow users to view and critique practice and examine alternative forms. Booth (2012) studied two robust online teacher networks and found that there needs to be multiple options for sharing knowledge and developing trust. Such options may include curated social forums that encourage active knowledge building and the exchange of information on classroom practice (Scardamalia and Bereiter 2014; Zeichner and Liston 2014). Moon et al. (2014) discussed design work that uses video cases of classrooms engaged in innovative practices, an online space for posting instruction in action, teacher-led expert facilitation, and links to authentic classroom products.

Additional literature suggests that discussion prompts are a particularly promising way of promoting collaboration, especially when they (a) provide specific structures for working together within the context of a given assignment (e.g., Hew and Cheung 2014; Yuan and Kim 2014) and (b) encourage learners to share expectations, goals, and personal stories (e.g., Booth 2012; Snyder 2009).

We used these findings to inform the development of the collaborative learning portions of the course and, in particular, the prompts that supported teachers' interaction. Our goal was to create an environment that supports the development of social capital, the importance of which is reviewed in the following section.

Designing for social Capital in Teacher PD

Building teacher networks, sharing knowledge and resources, and providing access to expertise can be collectively described as development of teacher social capital (e.g., Yoon 2018; Leana 2011). Unlike focusing on improving teacher human capital, which concerns developing knowledge and skills within an individual, focusing on social capital develops teaching capacities that can be acquired through direct and indirect relationships in social networks. To be more specific, Coleman (1988) discusses that this form of capital resides in the relations among persons and suggests that the quality of those relations (related to trustworthiness and trust) dictate what can be accomplished as a group, i.e., the greater the trust, the more that can be accomplished. Thus, the social ties, and the content and quality of those interactions all have a stake in the capital that is built and used to complete a task. Based on Adler and Kwon's (2002) seminal work defining the concept of social capital and the sources and processes involved in developing it, Coburn and Russell (2008) provide a useful categorization of social capital characteristics for teacher professional communities. This framework has been used in our previous research to understand the relative importance of teacher's access to human capital versus access to social capital in proffering successful learning experiences for students (Yoon et al. 2017b). Those categories are (1) *Tie quality*: How many people teachers talk to in relation to project implementation and the frequency of these interactions; (2) *Trust*: How willing teachers are to share information, which depends on how comfortable they feel in the community. In terms of capital and accessing resources, teachers may be motivated to share information about the project with the tacit expectation that they receive reciprocal information or resources; (3) *Depth of interaction*: The content of interactions that are more or less related to the project activities or goals. These interactions should be exchanges or reflections that lead to deeper conversations about and engagement with learning and instructional goals; and (4)

Access to expertise: The competencies and resources available in teachers' network connections as well as teachers' knowledge of these competencies and resources and their ability to access them.

Increasingly, research has shown that designs that are intentionally aimed at increasing teachers' social interactions through professional activities can improve the quality of teaching (e.g., Yoon and Baker-Doyle 2018; Farley-Ripple and Buttram 2018; Moolenaar et al. 2014; Penuel et al. 2018). In previous research, we demonstrated that through orchestration underpinned by social capital and teacher-learning theories, teachers' competence and confidence in instruction of *Next Generation Science Standards* (NGSS)-aligned computer-supported complex systems biology curricula significantly improved (Yoon 2018). In this current research, we attempt to reproduce this design with the aim of developing teachers' social capital in an online format to determine whether and how teachers are similarly positively impacted in this PD opportunity.

Measuring Transactivity

In this study we use the construct of *transactivity* to measure of the depth of social interaction among participants. Transactivity occurs when a learner engages with and builds on a peer's learning contribution or reasoning (Teasley 1997). From a theoretical perspective, a high level of transactivity in a collaborative context is indicative of valuable cognitive activities involved in knowledge construction (Teasley 1997). Importantly, higher occurrences of transactivity have been empirically tied to improved learning outcomes (e.g., Chi and Wylie 2014; Teasley 1997; Vogel et al. 2016). Beyond contributing to specific knowledge construction, transactivity also plays a valuable role in the guidance and organization of learner thought processes. For example, participating in transactive discussions can encourage learners to support their claims with evidence and to explain their reasoning. Furthermore, the development of probing questions may play a beneficial role in a learner's self-explanation of concepts (e.g., Weinberger and Fischer 2006). In the case of our online PD, transactivity analysis provides us with a direct, quantifiable measure of the depth of interaction among participants, a key aspect of social capital acquisition in PD. High levels of transactivity also provides insights into the other aspects of social capital. When peers interact in meaningful ways (i.e., *depth of interactions*), we may assume that there is an increase in *tie quality*. Furthermore, where a sense of community among participants is a prerequisite for collaboration in shared knowledge-building spaces (e.g., van Aalst, 2009; Fu et al., 2016), high levels of transactive discourse may also be indicative of high levels of *trust* among participants. Transactivity can also serve as an indicator of access to expertise, as teachers are able to ask questions and learn from the feedback of their experienced peers and peer facilitators.

A number of different frameworks for evaluating transactivity have been developed (e.g., Vogel et al. 2016; Weinberger and Fischer 2006). Weinberger and Fischer (2006) introduced a framework that outlines five hierarchical levels of argumentative knowledge construction. This framework begins with externalizations at the lowest level, progressing to elicitations, quick consensus building, integration-oriented consensus building, and finally conflict-oriented consensus building at its highest level. Vogel et al. (2016) divided transactivity into two categories, using the terms *dialogic transactivity* (building on others' ideas from a point of agreement or elaboration) and *dialectic transactivity* (building new ideas through conflict and resolution). In this framework, non-interactive knowledge construction falls under the term *constructive activities* (adding new knowledge to the discussion). In our analysis, we used an

adaptation of these two framings (described in more detail below) to investigate the extent to which transactive discourse was achieved and to discuss this in relation to the development of social capital. Because transactivity analysis has not been conducted in a self-paced asynchronous online PD context such as ours, this analysis can provide a valuable benchmark for future transactivity analyses of this nature.

A growing body of research has investigated how online spaces can be constructed to elicit transactivity and collaborative knowledge building. One promising scaffold is the use of collaboration scripts to guide discussion between learning partners (e.g., Noroozi et al. 2013; Vogel et al. 2014, 2016; Weinberger and Fischer 2006). Collaboration scripts are scaffolds that guide learners through sequential steps of productive collaboration by explicitly prompting learners to follow predetermined collaborative actions, such as paraphrasing a peer's contribution or asking critical questions (Noroozi et al. 2013). Research has found that collaboration scripts can help draw out greater levels of transactive discourse from learners (Noroozi et al. 2013; Vogel et al. 2014). However, concerns have arisen that overly structured collaboration scripts may too rigidly guide discussion and may inhibit other components of productive dialogue (Vogel et al. 2014; Weinberger and Fischer 2006). Our collaborative discussion prompts were designed to scaffold transactive discussion in a similar way to collaboration scripts, but they differ from these scripts in their more open-ended and less-structured nature. An analysis of their impact on transactive discussion in a self-paced online PD will provide a novel contribution to the literature on transactivity.

Methodology

This work represents a portion of research from a U.S. National Science Foundation (NSF) project funded to examine the ability to scale high-quality PD on a freely accessible online course platform. In this first phase study, we took a primarily exploratory approach, working with a small number of teachers to probe context developments in more detail than a larger-scale design would allow (IES and NSF 2013).

Context

This research encompasses a year's worth of design and development activities beginning in September 2017 and culminating in the delivery of a 6-week course offered to high school biology teachers in July and August 2018, with implementation support extending into May 2019. The course was structured around five biology curricular units that were developed in another NSF project that delivered PD in the face-to-face mode in the summers of 2012 and 2013. These units include agent-based complex systems computer simulations built in the StarLogo Nova modeling tool on the topics of Genetics, Evolution, Ecology, the Human Body, and Animal Systems. All the units require students to work through experiments that provide experiences in core scientific practices, as outlined in the NGSS, such as modeling; analyzing and interpreting data; engaging in argument from evidence; and obtaining, evaluating, and communicating information (for more details about these learning resources, see Yoon et al. 2016). Similar to the current project, activities in the face-to-face PD delivery mode were built on known characteristics of high-quality PD and teacher learning, including the development of teachers' social capital. Through two iterations we saw increases in teachers' satisfaction, confidence, and engagement with the curriculum and improvements in the

four categories of social capital, such as tie quality (see Yoon et al. 2017b and Yoon 2018 for more details on teachers' growth from PD).

Our task in the online PD delivery mode was to replicate the high levels of satisfaction, confidence, and engagement with the StarLogo Nova modeling curricula. We developed seven online modules that mirrored the topics that were investigated in the face-to-face PD. These modules are:

- (1) Introduction to the course and participants and facilitators
- (2) What are complex systems
- (3) Why modeling is a core scientific practice
- (4) What is scientific argumentation and evidence-based reasoning
- (5) How do the curricular materials fit into the NGSS
- (6) How are each of the simulations and corresponding biology units specified in detail
- (7) Conclusion to the course and framing for implementation

The activities were intended to span about 40 h of participation. With respect to designing for the characteristics of high-quality PD and teacher learning through building social capital online, we started with the four categories of social capital and mapped onto them (1) PD and teacher-learning characteristics and (2) design choices. As we undertook this mapping, we kept in mind the affordances and constraints of asynchronous online delivery. Table 1 outlines the details of this mapping.

Here we provide more details and examples of the mapping described in Table 1. First, from the research that we reviewed, we know that high-quality PD acknowledges teachers as knowers and agents of change (Cochran-Smith and Lytle 1999). Thus, we worked with teacher leaders from the previous face-to-face PD implementation as official members of the research team in design and development activities. They provided insights and feedback on all aspects of the online course design. We referred to them in this role as design collaborators (DCs). Again, from the literature reviewed, we know that effective PD fosters social relationships for peer-to-peer support (Moon et al. 2014; Zeichner and Liston 2014). Thus, the DCs also served as facilitators for the course, acting as peer experts, while prompts for the course were specifically tailored to encourage support among peers. Additionally, optimal teacher learning involves active sense making that can be anchored in practice that is made public to the community (Lieberman and Mace 2010). We translated this into the course design through in-class videos of the DCs implementing the curriculum, with prompts that encouraged participants to make connections to their own classroom practice.

The use of multiple categories of prompts were designed to promote various aspects of effective PD (e.g., collaboration and active sense making) in addition to overcoming the challenges highlighted in the introduction when participating in online asynchronous activities (e.g., lack of support for collaboration and social interaction). While we chose edX as the course platform due to its name recognition and well-developed scaffolds for instructional designers to construct online courses, the discussion forum tool was relatively underdeveloped in terms of supporting peer-to-peer interaction. As seen in Table 1, we included illustrative prompts that encouraged participants to interact with other participants (e.g., *Share one triumph in creating your model along with one unexpected moment. Then, leave some encouraging comments on other posts!*). This category of prompt, hereafter referred to as *collaborative prompts*, is most germane to the present study. However, the course also employed two other categories of prompts to support the development of teachers' human

t1.1	Table 1 Design Choices for Building Teachers' Online Social Capital		
t1.2	Social Capital Category	PD and Teacher Learning Characteristics	Design Choice for Online Delivery
t1.3	Tie Quality	Building relationships	<ul style="list-style-type: none"> • Online profiles to share professional and personal information Example: Write a post that describes your background (e.g., how long you have taught, unique skills or knowledge that might interest your classmates). After you have responded, use the forum to connect to a couple of other course participants by clicking "reply" to comment on their posts.
t1.4		Peer-to-peer support	<ul style="list-style-type: none"> • Prompts to seed norms of support (collaboration prompt) Example: If you were able to make a model (even if it doesn't totally answer your research question), please share a link to your creation along with the question you were trying to answer. (Remember you have to add the project to your public gallery in order to share it.) Share one triumph in creating your model along with one unexpected moment. Then, leave some encouraging comments on other posts!
t1.5	Trust	Orchestrating knowledge sharing	<ul style="list-style-type: none"> • Online space to upload and download teacher-initiated resources • Facilitators actively connecting individuals with germane ideas to other individuals
t1.6		Teacher as knower and agent of change	<ul style="list-style-type: none"> • Design of the course with teacher leaders who participated in the previous face-to-face PD. Met monthly with three teachers, whom we called "Design Collaborators" (DCs), to critically think through important aspects of PD and instruction.
t1.7	Depth of Interactions	Active sense making and problem solving	<ul style="list-style-type: none"> • Prompts that structure conversation around problems of practice implementation prompt) Example: Imagine your own classroom, what challenges do you see happening with your student population around building computational models? Think through some strategies with others.
t1.8		Utility in real school contexts	<ul style="list-style-type: none"> • Prompts that ask teachers to offer tried-and-true resources that they already use to teach scientific practices (e.g., scientific argumentation) (implementation prompt).
t1.9		Customization to teacher needs	<ul style="list-style-type: none"> • Self-pacing in the online mode to accommodate teachers' learning trajectories, with multiple forms of support to customize teacher needs (e.g., to take as long as they need to learn the StarLogo Nova programming language).
t1.10		Time to process new information	<ul style="list-style-type: none"> • Prompts that ask teachers to reflect on previous practice (implementation prompt) Example: Now that you have worked through Something's Fishy yourself, how do you see this as being different or similar to your approach to teaching about evolution? Write your thoughts in the discussion forum.
t1.11	Access to Expertise	Making practice public	<ul style="list-style-type: none"> • In-class videos of DCs implementing the curriculum in their classrooms with prompts to focus course participants on strategies that can lead to successful implementation.
t1.12		Access to professional peers	<ul style="list-style-type: none"> • DCs poised as experts who can problem solve with course participants. DCs instructed to monitor Discussion Forum conversations and chime in as needed. • Help forum that is monitored by course facilitators, including DCs who offer advice.

capital in their shared discussions. These categories were *implementation prompts* that asked participants to think about how the content of the PD could have utility in their real-school context (e.g., *What are the ways in which Emma helps her students get oriented to the technology and the task they are about to perform? Is there anything you would add when*

you do this with your own students?); and content prompts that asked participants to evaluate their understanding of the course content (e.g., Rauch describes several examples of emergent systems in the article. Briefly discuss how one example impacted your thinking about systems.).

The edX platform also does not provide an embedded resource sharing space (an important venue for teachers to share practical ideas such as lesson plans). Therefore, we created our own external resource (i.e., a Google spreadsheet with the ability to embed links that were connected to a Google folder that housed teaching resources). Additionally, although edX offered participants a way to share information about their professional experiences in their “profiles” section, this option was not interactive. Therefore, we created an activity that required teachers to discuss their areas of expertise and then post comments to others in order to seed interaction and sharing of experience.

Population

We worked with eight teachers from different geographic locations around the northeastern part of the United States. The teachers, who received a stipend, were recruited through a word-of-mouth campaign and selected because of their trusted connections to the research team. For example, one teacher came highly recommended from one of our previous PD participants, and two teachers had worked in previous years with the principal investigator of the project in their pre-service master’s degree program. They were selected on multiple criteria that included confidence that they would complete the course and provide critical feedback on their experiences; that they collectively represented a range of teaching experiences; and that they taught in schools that collectively represented a range of economic and ethnic diversity demographics. Of the eight teachers, seven were female and one was male. Teaching experience ranged from 0 to 20 years with an average of 8.3 years of experience. The schools they taught in ranged on the student-body low-income parameter from 7% to 69% with an average of 30.5%; and on the diversity parameter from 14% to 88% non-white student enrollment with an average of 44.8%. Additionally, three teachers who served as DCs and had previous experience implementing the biology curriculum units served as facilitators for the course. These DCs were chosen due to their enthusiastic implementation of the curriculum, their peer orientation to the participant teachers, and their availability for the run of the course. Of the three DCs, one was female and two were male. All three identified as White. Their teaching experience ranged from 12 to 25 years, though one had moved into administration. The schools they taught in ranged on the student-body low-income parameter from 15% to 61% and on the diversity parameter from 5% to 87%.

Data sources

To investigate the research goal, we collected three data sources: PD satisfaction surveys, teacher postcourse experience interviews, and transcripts of the discussion board posts.

Upon completion of the online course, teachers were administered a PD satisfaction survey to determine how well they liked the PD. This comprised 18 five-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 liked and did not like about the course and how they thought the course could be modified. Results from satisfaction surveys collected from two previous implementations of the face-to-face PD (in 2012 and 2013) were also used for comparison; those PD implementations had 10 teachers each.

Individual postcourse interviews were conducted with teachers to gather information about participating in the online PD mode. The 11 semistructured interview questions were constructed to understand teachers' experiences in the PD. Regarding this study, questions also explicitly probed participants' thoughts and experiences on design efforts towards building social relationships and social capital (e.g., *To what extent did you find the discussion aspect important to your learning? To what extent do you feel an online course like this depends on building a community within itself? Do you feel you received adequate support from the team and the DCs?*). Individual interview lengths ranged from 22 to 42 min, and the audio-recorded interviews were transcribed.

Throughout the course, participants were asked to respond to 55 prompts in the aforementioned categories of collaboration, implementation, and content. Twenty-three of these prompts occupied multiple categories (for example, an implementation prompt may also prompt participants to collaborate with each other and thus would occupy both categories of prompt). The total number of prompts in each category was as follows: collaboration = 19; implementation = 38; and content = 22. These prompts resulted in 694 coded utterances from course participants, including facilitators (159 utterances following collaboration prompts, 322 utterances following implementation prompts, and 216 utterances following content prompts). Because our facilitators were intentionally selected as peers to the PD participants and their interactions with participants represent the development of social capital for the participants themselves, facilitator utterances were analyzed alongside participant utterances. Facilitator utterances accounted for 50 of the 694 total coded utterances (7.2% of the total coded utterances).

Data analysis

To analyze the data, we used a mixed methods approach, looking for overarching trends and triangulating between the three data sources. To determine teachers' satisfaction levels with the course, average Likert-scale responses were calculated for all 18 items on the PD satisfaction survey and then aggregated responses in the three areas of (a) overall course satisfaction, (b) module construction and delivery, and (c) usability of materials in specific teaching activities. The open-ended responses from the satisfaction survey were used to provide more details about the Likert-scale responses.

Transcribed interviews were qualitatively analyzed for comments that shed light on teachers' experiences related to the four social capital categories listed in Table 1. We were interested in understanding to what extent our design efforts paid off in terms of teachers' learning and participation in the online PD mode. To parse teacher interview responses, we developed the social capital coding scheme found in Table 2. The interview analysis was conducted in two stages. First the interview transcripts were read by two researchers to identify comments that were related to any aspect of the social capital framework. While there were responses from direct questions asked about their building of social connections, the full transcript (that included responses to questions not specifically about social capital) was

analyzed through the use of code words such as discussion, community, or sharing. In total, 73 comments were identified (this number represents 37% of total interview comments). To obtain reliability on the coding scheme, two doctoral students were trained and then independently coded 16 (~22%) of the teacher comments, who were also asked to evaluate the overall tone of the comment to determine positive versus negative value. A Fleiss Kappa test returned an acceptable 0.84 reliability score. Thereafter, the rest of the 73 comments were coded by one researcher and some were double coded, which resulted in 81 independent codes. Examples are included in the table.

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Table 2 Social Capital Coding Scheme for Interview Data

Social Capital Category	Code Definition	Example
Tie Quality	Represents mechanics of teachers' communication and their motivations. It responds to how and whether or not ties were built in the online mode	(Positive) <i>What got me-- one time I opened one and it was replying to me and I was like oh, no. I was like oh, I really have to go back and make sure people don't think I'm ignoring them.</i> (Negative) <i>I think in some places [the discussion prompt] was really helpful but it didn't need to happen all the time and it felt a little bit like I wasn't able to decide [what to] prioritize because it just asked me to do it all the time.</i>
Trust	Reflects how teachers felt about the community. Did they feel comfortable? What added to or detracted from that comfort?	(Positive) <i>I think having the teachers who were in the implementation videos and the teachers of the course, I guess maybe the administrators of the course, the fact that they were interacting felt really authentic to me. It feels like something that made it a lot more personal of a project to be a part of.</i> (Negative) <i>I don't know if I would call it a community. I guess it depends on how you define [it]. I don't feel like had individual relationships with people.</i>
Depth of Interactions	Refers to the content of communications. What did teachers communicate about and what was valuable to them? Did the PD allow for deep level interactions?	(Positive) <i>And then it's helpful to hear...how they taught argumentation. How they taught modeling. How they taught some of these other topics.</i> (Negative) <i>It seems we're all going to be doing these StarLogo simulations, probably at different times of the year....So, unless we're doing them at the same time, I think it's gonna be a little harder with the [communication] aspect of it. Probably at the end of the year maybe, or the end of each semester - we could kind of say what worked for us, what didn't.</i>
Access to Expertise	Refers to teachers' access to the project team and the DCs as well as their perceived value of access to course resources.	(Positive) <i>Thinking about implementing things, being able to discuss with the other teachers who were in the videos [DCs]. Being able to hear from them what it looks like in their classroom was also really cool.</i> No negative comments were made by teachers in this category.

Participant utterances in the discussion boards were qualitatively mined for levels of transactivity among participants. A coding scheme was adapted from transactivity coding manuals developed by Vogel et al. (2016) and Weinberger and Fischer (2006). Our coding scheme categorized each discussion post into one of four learning activities (constructive activities, general elicitations, dialogic transactivity, and dialectic transactivity) or a “rest” category that constituted the fifth category. Building on previous empirical evidence (e.g., Chi and Wylie 2014; Vogel et al. 2016), each category was assigned a hierarchical score from 1 to 5, with 1 representing the lowest levels of transactive discourse and 5 representing the highest. Table 3 provides specific definitions and examples of each category. The unit of analysis was a complete discussion board post.

To obtain reliability on the coding scheme, two doctoral students were trained and then tasked with independently coding 87 (approximately 20% of total posts) of the

Table 3 Definitions and Examples of Transactivity Codes

Social Capital Category	Code Definition	Example(s)
Level 5: Dialectic Transactivity	Contributions that directly interact with and take into account a partner's constructive contributions from the perspective of disagreement or critique rather than agreement. This may include counter-arguments, critiques, the integration of previously opposing contributions made by learning partners, or probing with questions (Vogel et al. 2016).	“I would disagree because there is a centralized command from the brain and according to the complex system format, there is no single leader who controls.” “Yes, but I think the brain is an example of a complex system itself.”
Level 4: Dialogic Transactivity	Contributions that directly interact with and take into account a partner's constructive contributions from the perspective of agreement or elaboration rather than disagreement or critique. This may include elaborating on a partner's ideas, explicitly agreeing with a peer, integrating a partner's advice into the learner's future outputs, or probing with questions (Vogel et al. 2016).	“I like how you mention the opportunity for data visualization here. I was thinking I could ask my students to run this simulation and create a large graph of their findings to share with the class.” “I think using the lactose idea to frame enzymes is great. I too use the kits.”
Level 3: General Elicitations	Contributions that are made with the intent of initializing transactive discussion with peers. In the discussion forum, these occur when learners engage with the community at-large and specifically elicit feedback or follow-up discussion (Weinberger and Fischer 2006). These contributions are significant in a discussion forum format due to its unstructured nature, as posts may not always receive timely responses, and participants at times must actively seek out learning partners.	“It seems possible to increase or decrease the temperature and pH to help in our lessons. Please give me an idea how this is possible.”
Level 2: Constructive Activities	Contributions in which a learner generates or produces outputs or products beyond what is provided in the learning material. Constructive activities do not take another learner's contribution into account (Vogel et al. 2016).	“Although I do not teach enzymes in my class (other than briefly mention how they relate to catalysts), I can see how the simulation could be helpful. I especially like how some of the monosaccharides are cleaved off in the absence of the enzyme.”
Level 1: Rest	Posts that do not fall in the other four levels. These may include instances of copying and pasting, off-task statements, or interactions that are strictly social in nature.	“Great job guys.” “It seems we keep following each other! Hahaha!!”

teacher discussion board posts. A Cohen's Kappa test returned a 0.98 reliability score. Thereafter, all remaining discussion board posts were coded by one researcher. A single-factor ANOVA analysis was conducted to determine if the variation in transactivity levels across prompt types was statistically significant. A post-hoc Bonferroni test was then conducted to identify the source of the variation between responses in prompt types.

Results

High teacher satisfaction of online PD

Findings from the usability survey showed that the online teachers on average rated all 18 Likert-scale items between 4.5 and 5, which indicated very positive PD experiences. Aggregate averages in the areas of overall course satisfaction, module construction and delivery, and usability of materials were 4.60 ($SD = 0.57$), 4.78 ($SD = 0.42$), and 4.70 ($SD = 0.62$), respectively. As previously noted, past research has shown that teachers are often dissatisfied with their PD experiences (TNTP 2015) and with respect to online learning, dissatisfaction for various reasons has led to a participation gap (e.g., Chen and Huang 2019). Thus, we believe that teachers' high satisfaction ratings demonstrated success in engaging teachers positively with the course. Although the rating in the area of overall course satisfaction was the lowest of the three areas measured, this 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 that could 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 Discourse 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 high satisfaction ratings indicate that the PD was a success from the view of the participants and provides a positive foundation on which to conduct the social capital analysis.

Positive and negative impacts of social capital course design

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The teacher interview analysis showed 26 comments related to the category of tie quality, 17 related to the category of trust, 16 related to the category of depth of interaction, and 22 related to the category of access to expertise. Figure 1 shows the breakdown in terms of positive and negative comments in each category.

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For tie quality and depth of interaction, the frequency of positive comments outnumbered that of the negative comments. Moreover, teachers did not offer any negative comments in the access to expertise category. In all three of these categories there is evidence from the comments that the design choices led to these positive views. For example, in the category of tie quality, the following quote shows some support for the goal of building relationships within the course.

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I found a community and community connection within that small population and...I feel that...I resonate better with this person and you start following that person. That...is like really a very valuable thing.

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Likewise, in the category of depth of interaction, through their connections in response to implementation prompts we saw evidence of active sense making and reflections pertaining to teachers' real world teaching contexts. The next two quotes illustrate this shared struggle about challenging content and difficulties in integrating technology into instruction.

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The enzyme one, because that's always a hard concept to teach. I felt like there was a lot of discussion for that one. Because we all sort of agreed that it was a very hard concept to give me a better idea of like, if I was to introduce this to my students... they were raising personal challenges that they had with the software that I can easily see my students also having. So, it was really helpful to kind of see that wide range of responses to give me a gauge of like, maybe a little bit of what I can expect when I do it with my students.

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In the category of access to expertise, the following comment encapsulates the overwhelming positive result of the design choice related to making practice public through the videos of DCs:

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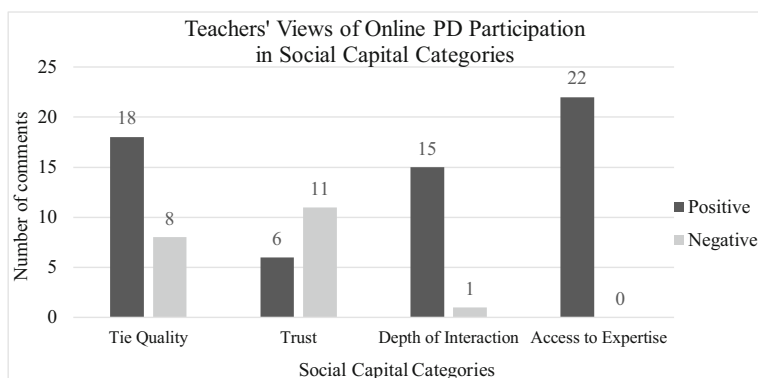


Fig. 1 Comparison of PD Usability survey results

I think module six was my favorite because again, you're seeing it like real teachers implementing it, real students, how they're interacting with it and then the thought questions where they were like, "How does this look different from the way you teach this topic?" I think that really got me to think about like, "Oh wow! I'm not teaching it in the best way for deep student understanding and this is really going to help my students understand this more."

Other teachers found the help forum and quick responses from course facilitators extremely helpful to their own learning. The following two examples illustrate this point.

I also really enjoyed that there was a single post or a separate forum for asking for help, which I was able to use when I had trouble with the Termite challenge module.

Yes, whenever I did post like a specific question, I got answers very quickly so I definitely got enough support.

Despite these positive results, not all participants felt that they were able to build strong relationships in the online mode as is evidenced in the following quote.

I was responding to these people who ... although, I like read their short bio and knew basically where they were teaching, I didn't have enough pre-existing knowledge of them to like really dig in to those kind of meaty conversations that I think you can get in an in-person PD.

Comments such as these highlighted areas for further improvement. In this case, the design choice to have participants post online profiles and interact with them did not fully support our goal of improving tie quality.

Furthermore, where the results demonstrated greater negative comments than positive comments in the category of trust, similar to the survey responses, teachers offered reasons for why they felt that a feeling of community was harder to construct. One teacher said the following:

Every time I read a forum post that I felt like I could connect to, I don't feel like there was...that in-person community, you remember who that person is and then there is...a relationship that gets built there. I was never able to remember who said those particularly relevant things and so it was more like let me look at this bank of possible interpretations and they didn't feel like people to me but it did feel like there was a diversity of thought that I had access to and that aspect of a community felt real to me.

For this teacher, the online mode made it more difficult to "remember" who made specific posts, which may have led to challenges in relationship building. However, as she notes, this enabled her to focus on the "diversity of thought" that she appreciated having access to. Another teacher offered that the heterogeneity of teaching contexts might have posed barriers to connecting with others. She stated the following:

I'm teaching at a lower income...really heterogeneous class of 9th grade Bio...the age level matters, the demographic matters, the learning levels matter. So, if I could have known who else was teaching in a similar context to me then maybe a relationship could have been built there.

Transactivity analysis

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The average transactivity score across all posts was 2.6 out of a possible 5. Constructive activities were the most common post type, accounting for 69.2% of all utterances. Dialogic transactivity was the second most common post type, accounting for 23.9% of utterances. The remaining three categories (dialectic transactivity, general elicitations, and rest) each accounted for less than 5% of all utterances, with dialectic transactivity occurring in less than 1% forum posts.

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Utterances in content prompts had an average transactivity score of 2.7, with constructive activities accounting for 63.9% of posts and dialogic transactivity accounting for 26.9% of posts. Utterances in implementation prompts had an average transactivity score of 2.5, with constructive activities accounting for 72.4% of posts and dialogic transactivity accounting for 24.2% of posts. Utterances in collaborative prompts had an average transactivity score of 2.9, with constructive activities accounting for 45.9% of posts and dialogic transactivity accounting for 38.4% of posts. Across all prompt types, less than 10% of the posts were coded as dialectic transactivity, general elicitations, or rest. Figure 2 shows the breakdown of each category by prompt type.

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The ANOVA analysis indicated there was significant variation in the transactivity levels between the three different prompt types, $F(2,694) = 9.618$, $p < .00001$. The post-hoc Bonferroni test indicated that the variation in transactivity was attributable to the higher percentage of transactive responses in the collaborative prompts, which was significantly higher than responses in the content prompts ($p = 0.03$) and the implementation prompts ($p = 0.0001$). No significant difference in transactivity levels was found in responses between content and implementation prompts ($p = 0.24$).

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These results show that the prompts coded as collaborative were significantly better at eliciting transactive discussions than those that did not include explicit collaborative goals. We also saw evidence in the interviews that corroborate this finding such as the comment below.

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I think [the prompt to collaborate] was definitely helpful. I think the course would have felt, and you know would have functionally been, completely independent learning if it hadn't had [that] discussion component.

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Some teachers discussed including even more collaborative prompts:

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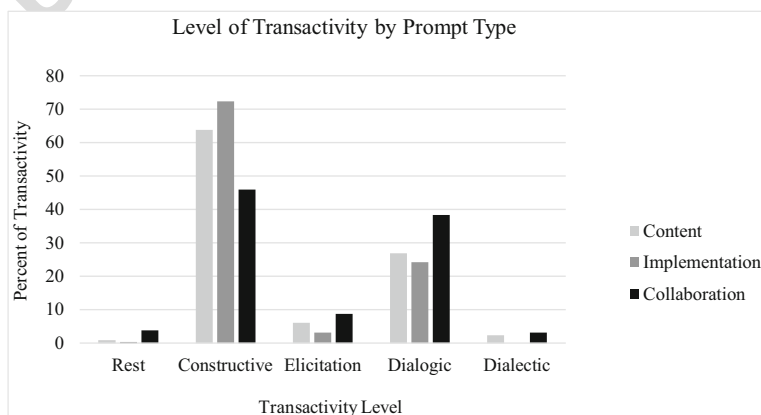


Fig. 2 Transactivity level based on prompt type

A couple more prompts where the requirement is like you have to go at least twice and respond to two other people and then comment once, those kinds of things. That's just my own opinion that would get people more involved.

However, the findings of the transactivity analysis showed that very few conversations reached the level of dialectic transactivity, which may be linked to the issues of trust that we found in the social capital analysis. This is what one teacher said in their interview.

Personally, like I don't really feel comfortable pushing back on an idea or challenging an idea or raising an alternative point of view unless I feel comfortable in the community. Most of the time, I feel like it's just gonna be, if I don't know people very well—teaching is so personal, and teachers take their work so personally, which is understandable—that I am always very careful about like disagreeing with people who I don't know very well.

In the next section, we discuss the main findings of our study and offer some next steps for this research.

Discussion

The findings from this exploratory research are quite instructive. First, the satisfaction surveys showed that teachers liked the course and found the resources to be usable in their instruction. These scores contrast, in a positive way, with widespread teacher perceptions of their general PD experiences—namely, a lack of utility in real school contexts, poor delivery quality, and lack of customization to their needs (Hill 2009, 2015; Hodkinson and Hodkinson 2005; TNTP 2015). We hypothesize that several of the designs for building social capital supported this result, for example, using an affordance of the online mode that enabled the activity of making practice public (Hatch, 2006; Lieberman and Mace 2010) in which the DCs were able to share examples of their teaching practices through videos and commentary. All course participants said that the video footage of expert teachers enacting the curriculum was very helpful. Moreover, the fact that these experts acted as facilitators in the course allowed them to respond quickly to participants' posts in the help forum. This level of support was noted and appreciated by all teachers. This access to expertise shows the potential for online PD to address the dearth of access to professional peers and geographic isolation issues highlighted in recent PD policy documents (e.g., Peltola et al. 2017).

The transactivity analysis provided here sheds light on manifestations of social capital in asynchronous online PD and can be used to guide and benchmark future analyses of transactive and collaborative discussions in such PD environments. The higher levels of dialogic transactivity seen in response to the collaborative prompts in the discussion forums indicate that those prompts were successful in promoting greater depth of interaction, tie quality, and access to expertise relative to noncollaborative prompts. This transactivity indicates that participants were more deeply interacting with each other's contributions and reasoning during forum discussions, and the sheer number of transactive replies between participants following these prompts is indicative of the peer-to-peer support highlighted by Coburn and Russell (2008) as tie quality. The high levels of transactive replies by a peer teacher or peer teacher facilitator in these prompts is also emblematic of access to expertise, given the wealth and diversity of practical

experiences of teachers participating in the PD, as teachers offer feedback or additional insights in response to the contribution of other teachers.

As Fishman et al. (2013) highlighted, the design and development of effective PD, regardless of venue, is costly and time-consuming. Although research indicates that interaction among PD participants can play a crucial role in PD outcomes (e.g., Zeichner and Liston 2014), nurturing that interaction, whether through discussion forum moderation or other scaffolds, can be a burdensome process. That the collaborative prompts yielded significantly greater depth of interaction among participants in our PD is an important finding due to the simple and low-cost nature of these prompts. Generally speaking, the characteristic that most likely distinguished a collaborative prompt from a noncollaborative prompt was a quick reminder at the end of the prompt for participants to engage with peers (i.e., “please read at least one or two other posts and respond”). These short phrases, attached to the end of approximately one third of the discussion prompts, were positively associated with significantly different levels of transactive discussion among participants. These prompts were also recognized by participants as being helpful in building interaction, as shown in the interview data.

The lack of dialectic transactivity in the discussion forums is also noteworthy from a social capital perspective. As previously discussed, dialectic transactivity is hypothesized to enable learners to partake in valuable knowledge-building processes as they reconcile contradictory ideas or perceptions (e.g., Teasley 1997; Vogel et al. 2016), and collaborative knowledge-building processes likely rely on a sense of community and trust among participants (e.g., van Aalst, 2009). The fact that we found very little discussion occurring around points of disagreement or critique may indicate a shortcoming of trust-building in our PD experience, which we clearly found in the social capital and interview results. We hypothesize that this may be due to the asynchronous and impersonal nature of discussion forums. Responses from peers were not always timely, and participants could not always be certain that another teacher would respond to a given post. Furthermore, as we saw in some teacher’s interviews, concerns about being offensive or impinging on professionalism when teachers do not know each other very well could also discourage critical posts. Without a well-developed sense of community and trust, teachers may not have felt comfortable offering critiques. Prompts that explicitly encourage participants to make counterarguments in order to further knowledge building, may reduce this hesitancy and provide teachers with the license to engage in dialectic transactivity. But additional research is needed to test this hypothesis.

We also hypothesize that the lack of individual connection, for some teachers, may be mitigated when the number of course participants grows, as it may increase the likelihood that teachers are able to connect with other teachers from comparable teaching contexts. Clearly, a limitation of this research is that we worked with a small number of teachers, and we know that interactional qualities will look different with larger numbers. However, we were intentional about working with a smaller number so that we could examine in some detail how they responded to the social capital PD design. Greater numbers will also ensure that more teachers are working in the course at the same time, which might inform a trade-off that we may need to make in terms of addressing the teacher time issue (flexible self-paced activity vs. timed activity).

The average transactivity level of 2.55 also warrants some discussion. As indicated in Fig. 2, while collaborative prompts contained significantly more transactive discussion among participants relative to the other prompts, posts in response to all three types prompts (i.e., collaborative, implementation, and content) contained more constructive posts than any other

transactivity level. In these constructive posts, participants tended to work more independently, either engaging directly with the learning materials in the PD module or thinking critically about how concepts could relate to their own personal classrooms. In these posts, which were coded as 2 out of a possible 5, transactive discussion between participants was often supplanted by inward reflection. We do not believe the seemingly low transactivity score for those posts is representative of a failing to produce social capital though. Given the reasonable assumption that a peer will read it, the act of voluntarily posting even a constructive post is inherently a manifestation of tie quality and depth of interaction, though it is not as explicit in this regard as dialogic or dialectic transactivity. The general presence of these constructive posts also serves to support access to expertise for any other teacher with access to the knowledge contained in those posts. We believe that higher transactivity levels are indicative of higher levels of social capital, but we believe further research into social capital development and transactivity analysis in online asynchronous PD is needed to provide benchmarking for what exactly low or high average transactivity levels look like in this context. In general, effective PD should offer participants a range of diverse learning activities and knowledge-building opportunities (e.g., Darling-Hammond et al. 2017). From this perspective, providing a balance of reflective and interactive discussion prompts was likely a good design decision in this context, but future research should examine the impact that variation in the quantity of different types of discussion board prompts has on PD outcomes.

This study's findings suggest that a social capital and teacher learning framework might be used to overcome some of the critical issues in offering effective teacher PD online. Our next steps are to (a) iterate the PD design to include greater focus on developing trust among participants and (b) deliver the course with larger numbers of teachers to investigate to what extent teachers' satisfaction and social capital responses differ at larger scales. In the summer of 2019, the course was launched on edX, with 260 teachers in 20 countries and 17 U.S. states enrolled. The course had a completion rate of 16% (41 teachers). Data from the teachers who completed the course are being analyzed similarly to the data from the 2018 run and will be used to compare and expand the findings from this study.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no known conflicts of interest.

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