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Understanding how to design online professional development environments that support mathematics teachers in developing mathematical and pedagogical knowledge is more important than ever. We argue that productive social and sociomathematical (SM) norms have benefits for teachers learning mathematics in online asynchronous collaboration and that particular patterns in interactions can create context for the emergence of such norms. We employed social network analysis to compare the emerging social networks of two iterations of an online asynchronous professional development course focused on functions to understand whether particular scaffolds can support the emergence of specific patterns of interactions. Results suggest that evidence-based noticing and wondering can impact the "small world" properties of a social network and associated potential for the emergence of social and SM norms.

Keywords: Professional Development, Online and Distance Education, Teacher Knowledge, Noticing and Wondering

Objectives and Purposes

Our work focuses on the design of online professional development environments that support teachers in collaboratively developing mathematical and pedagogical knowledge. One challenge associated with such design endeavors is moving mathematics teachers from "show and tell" to collaboratively building mathematics knowledge together (Stein, et al., 2008) by participating in productive social and sociomathematical (SM) norms (Cobb et al., 2001). We argue that there can be a connection between the evolution in particular patterns of teachers' interactions in online asynchronous collaboration and potential for the emergence of social and SM norms. The current paper documents evidence-based noticing and wondering (EB-NW) scaffolding the emergence of these particular patterns of interactions in mathematics teachers' online asynchronous collaboration, where the focus of collaboration was on developing foundation reasoning skills for understanding the concept of function.

Theoretical Framework

Social norms and their mathematics-specific counterpart SM norms – accepted and expected regularities in mathematical dialogue – have benefits for collaborative mathematics learning in both face-to-face (Clark et al, 2008) and online mathematics teacher professional develop. Such norms can guide generative and collaborative mathematical activity that includes explaining and justifying one's reasoning, communicating the meaning of mathematical ideas, and critiquing colleagues' mathematical reasoning (Elliot et al., 2009; van Zoest et al., 2012). As such norms emerge, they create conditions for teachers learning to make contributions to collaborative mathematical activity that align with these generative forms of participation (Cobb et al., 2001). Further, teachers participating in productive norms provides them with experiences learning mathematics in a discourse-centered environment and these norms can become tools for building similar norms in their own classes (Clark et al., 2008; Tsai, 2007). Thus, it is important to understand how to support the emergence of norms in online professional development settings –

a setting that can be scaled to increase the impact of professional development on teachers' mathematics instruction.

Mathematics teachers accessing and engaging with their colleagues' mathematical reasoning is important for the emergence of social and SM norms in online settings. A key difference between building norms in face-to-face and online settings is how one gains access to or listens to their colleagues' ideas (Dean & Silverman, 2015). In face-to-face settings, teachers can listen to a mathematics conversation simply through proximity to others; in online asynchronous collaboration, researchers must define "listening" in a different way (e.g., see Wise et al., 2013). In our work, we define listening as explicit interaction with colleagues' mathematical reasoning by reviewing and responding to another's post. Because of the publicity and permanency of teachers' contributions to online asynchronous collaborative environments, reviewing and responding to another's post can include extended reflection on a specific way of reasoning in the post. Therefore, an individual's mathematical reasoning in an online environment can become a scaffold that supports others in learning to engage in generative contributions and/or interactions in the online space. Regularities in mathematical reasoning can emerge when mathematics teachers are reflecting on, taking up, and trying out their colleagues' mathematical reasoning. This process can result in specific ways of reasoning becoming more visible in an online space (Borba et al., 2018), which increases the potential influence of specific reasoning on collaborating teachers' future use of reasoning (Lave & Wenger, 1991) – if they are interacting with colleagues' in the online space.

Small world networks can create context for interaction and, ultimately, the emergence of social and SM norms in online professional development settings. The concept of a small world - what is commonly thought of as the "six degrees of separation" between any two people in the world - is often applied to studies of social networks. Formally, a small world is a sparsely connected social network - a set of nodes (people) and edges (an interaction between two people) - with both high local clustering and short paths of connections between individuals in the network (Watts, 1999). In the context of online asynchronous collaboration via discussion boards, a social network with a minimal average path length means that mathematics teachers are accessing and engaging with a large proportion of their colleagues' mathematical reasoning. We argued above that access and engagement with mathematical reasoning can create context for the emergence of social and SM norms because of the potential for specific ways of reasoning to diffuse through the network. Therefore, we argue that the "small worldness" of mathematics teachers' social network is an indicator of the potential for emerging social and SM norms in online asynchronous collaboration.

Further, we argue that EB-NW can scaffold the emergence of small worlds. Noticing and wondering is receiving increasingly more attention in the literature (e.g., Dobie & Anderson, 2020). We are currently engineering a virtual assessment environment that scaffolds a specific type of noticing and wondering – EB-NW, which is noticing and wondering that is explicitly connected to a colleagues' thinking. The environment enhances typical online asynchronous discussion forum conversations by scaffolding EB-NW with two key design features: a selection tool that allows teachers to highlight specific aspects of colleagues' mathematical reasoning and a commenting tool that supports noticing and wondering that is explicitly connected to the selections (the evidence). Our past work has documented the effectiveness of the environment to support teachers in engaging with the details of their colleagues' mathematical reasoning and providing generative feedback that moves beyond a focus on the correctness of their colleagues' solutions (Matranga et al., 2018). Further, we have found that teachers are less likely to provide one another evidence-based and generative feedback when online asynchronous collaboration is scaffolded by discussion forums (Matranga, 2017). Thus, we argue that technologically scaffolded EB-NW can increase the proportion of interactions in an online asynchronous collaborative setting that include mathematics teachers' explicitly engaging with colleagues' mathematical reasoning, thus enhancing the small world*ness* of a social network and associated potential for emergent norms.

Methods

We investigated the small world properties of mathematics teachers' evolving social network in two iterations (C1 and C2) of an online asynchronous professional development course focused on understand the behavior of functions. The course includes eight weekly problem-solving modules, each featuring a set of mathematics tasks and scaffolds to support participant engagement with the mathematics and interaction with colleagues. The modules included an initial period of individual problem solving and then a period specifically devoted to peer-to-peer collaboration. The two iterations of the course differed only by the collaboration scaffolds provided – the first utilized traditional discussion boards (C1), while the second utilized the virtual assessment environment designed to scaffold EB-N&W and mediate teachers' collaboration and interaction (C2). Our research question is: How does participants' engagement with and access to colleagues' mathematical reasoning differ between C1 (n = 16) and C2 (n = 23)? In particular, we seek to understand if one course and associated scaffolds more effectively support participants' engagement with and access to colleagues' mathematical reasoning.

Social Network Analysis (SNA), an analytical tool that can be used for quantifying patterns in interactions (Light & Moody, 2020), and statistical analysis was used to examine and compare the extent to which the networks exhibited small world properties. Accordingly, we modeled C1 and C2 as a set of nodes (participants) and directed edges connecting nodes (a response from one participant to another). We used the SNA metric of network efficiency to examine the small world properties of the network because this metric can provide insight into the extent to which network members are accessing and engaging colleagues' mathematical reasoning (Latora, & Marchiori, 2002). Specifically, network efficiency is quantified by counting the minimum number of edges required to connect one colleague to another. The individual degrees of separation for each pair is used to calculate the network efficiency by summing across all pairs and normalizing results. Network efficiency ranges between 0 and 1, where 0 is a minimally efficient network (a completely disconnected network) and 1 is the most efficient network (a fully connected network - the smallest possible world). We extracted participant interactions (358 for C1; 385 for C2) from the courses, generated cumulative interactional datasets for each week of the courses (e.g., the week two data set from C1 included interactions from week 1 and week 2 of C1), and then imported the data into UCINET to assess the network efficiencies.

SNA measures are highly sensitive to the number of nodes in the network (Wasserman & Faust, 1994). Therefore, in order to compare the two courses and interpret our results, following Opsahl et al. (2017), we modeled 50 different hypothetical networks with the same number of nodes (participants) as the courses under investigation but with edges (interactions) randomly distributed between pairs of nodes. The mean efficiency of these hypothetical networks, referred to as the *average random graph network efficiency* (RGNE), allowed us to compare the observed network efficiencies from each week of C1 and C2 to RGNE for each week of each course, where engagement with and access to mathematical reasoning was randomly distributed throughout the network. This included verifying that the network efficiencies of each set of 50 hypothetical networks were normally distributed and then calculating significance levels by comparing the observed network efficiency from each week of each course to the corresponding RGNE.

Results

Table 1 presents results for the observed network efficiency (O), the RGNE, and the corresponding p-values when comparing the observed network efficiencies to the RGNE. In both courses, the network efficiencies increased throughout the course, which is expected because participants had increased opportunities to access and engage with colleagues' reasoning as the course progressed. The network efficiency of C1 remained larger than C2 throughout the course. Further, the network efficiency of C1 was significantly lower than RGNE for weeks 3-8 *($p <$ 0.05)*, while the network efficiency of C2 was not significantly different from the RGNE for weeks 1-7. However, the network efficiency for C2 was significantly lower than RGNE after week 8.

Table 1: Week by week observed network efficiency, RDNE, and p-values

	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
O-C1	.140	.321	.431	.465	.528	.570	.613	.630
O-C2	.055	.138	.301	.366	.395	.444	.537	.548
RGNE-C1	.112	.336	.489	.534	.577	.623	.646	.664
RGNE-C2	.054	.113	.276	.377	.416	.472	.549	.564
***P* - C1**	0.129	0.374	0.015	0.001	0.003	1.1E-06	3.2E-06	3.2E-09
***P* - C2**	0.396	0.221	0.289	0.351	0.235	0.097	0.191	0.026

Discussion

The results of the analysis indicate that for the majority of the course (week 3-8), C1 had a significantly lower network efficiency than would be predicted by the RGNE, while the network efficiency of C2 was not significantly different than the RGNE. Watts and Strogatz (1998) note that a small average path length (i.e. higher efficiency) is one characteristic of randomly generated graphs and, as a result, the C2 network has small world characteristics. This result provides evidence that C2 (scaffolded by technologically supported EB-N&W) more effectively supported participants' engagement with and access to colleagues' mathematical reasoning throughout the "meat" of the course, increasing the likelihood for social and SM norms to emerge. Implications of this study include (1) the design of online teacher professional development environments with scaffolds that support teachers in connecting their N&Ws to evidence in their colleagues' reasoning when providing feedback, and (2) a methodology that can increase the scale of rigorous SNA studies of collaborative professional development, from examining single implementations of professional development to comparing multiple iterations of the same professional development as well as across professional development programs (Borko, 2004). Our plans for future research include expanding the current results to examine the specific social and SM norms that emerged in C1 and C2 as well as the specific role of EB-NW in scaffolding the emergence of norms.

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