Examining Interactions between Collaborative Professional Development, Science Teachers' Knowledge, and Students' Reasoning

Patrick J. Enderle[1], Kari L. Roberts[2], Jennifer Schellinger[3], Sierra Morandi[3], Harini Krishnan[3], Ruveyde A. Kaya[3], and Sherry A. Southerland[3]

Georgia State University[1], High Magnetic Field Laboratory[2], and Florida State University[3]

Objectives

Recent educational reforms conceptualize science classrooms as spaces where students engage in Science-as-Practice to develop deep understandings of scientific phenomena. When students engage in Science-as-Practice they are constructing explanations, arguing from evidence, and evaluating and communicating information to develop scientific knowledge (NGSS Lead States, 2013). This process of learning requires a focus on productive science talk in which students grapple with and socially negotiate their ideas (Kelly, 2014) through interactions involving talk, joint attention, and shared activity aimed at building, negotiating, and refining new understandings of phenomena and relevant science concepts (Ford, 2015; Michaels & O'Connor, 2012). Productive talk requires the 'nimble' involvement of the teacher to help students productively contribute their ideas to the class and use them as resources to drive instructional activities supporting the development and refinement of more sophisticated scientific understandings (Christodoulou & Osborne, 2014; González-Howard & McNeill, 2020).

Professional development (PD) experiences can support teachers in learning about implementing innovative instruction aligned with the Science-as-Practice goals (NASEM, 2016; Wilson, 2013). Research describes effective PD as that which positions teachers to focus on specific subject matter content; engages teachers in active and coherent learning; stretches over time and with sufficient duration; enables the collective participation of teachers; provides opportunities for collaboration; and uses artifacts of practice (Southerland et al., 2016; Garet et al., 2001; Wilson, 2013). Voogt and colleagues (2011) build on opportunities for collaboration to describe that such efforts must include design so that "teachers create new or adapt existing curriculum materials in collaboration with each other" (p. 1236). Further, Gomez and colleagues (2015) proposed that learning through design enables teachers to make new practices work. As such, collaborative design is situated in real--world teaching contexts and positions teachers as active learners within the context of their classrooms. However, the majority of PD experiences for science teachers do not reflect these established ideas. According to Banilower and colleagues (2018), only about 50 percent or fewer teachers reported having had opportunities to engage in such experiences.

The nature of what 'active' and 'collaborative' PD experiences entail remains an open question as researchers continue to explore multiple models. Indeed, collaborative design remains an open question with much of the research to date focusing on curricular modifications teachers make, and little focus on how collaboration changes the knowledge, learning, and practice of teachers. The goal of this research is to understand how including focused collaborative design activities in an extended PD experience influenced participating teachers' and students' learning. We explore two models of PD, one including collaborative design and one including an approach infused with nature of science concepts, both having a central focus on supporting students to engage in productive science talk. We compared student learning outcomes related to reasoning across teachers who participated in one of the two versions of PD. We chose to focus on students' reasoning rather than just knowledge because current Science-as-Practice visions for classrooms aim to develop these proficiencies in learners (Ford, 2015; Stroupe, 2014; Kind & Osborne, 2017). The following research questions guided this study:

1. Are there differences in student learning outcomes (Reasoning) for those students whose teacher participated in one of two PDs focused on productive talk?

2. What are the relationships between a teacher's personal domain (Epistemic Orientations towards Teaching Science and Pedagogical Content Knowledge of Argumentation) characteristics and student learning?

Theoretical Framework

The Interconnected Model of Teacher Professional Growth (IMTPG) (Clarke & Hollingsworth, 2002) provides a useful framework for studying how teachers' beliefs and affect, external professional development, classroom experiences, and consequential outcomes interact as teachers learn over time. This model identifies four critical domains that can reciprocally influence each other. The *Personal Domain* encompasses teachers' knowledge, beliefs, and attitudes toward teaching. The *External Domain* concerns the external input teachers receive related to their instruction and the associated pedagogical models and resources, including professional development. A teacher's classroom and their efforts at implementing new strategies and resources comprise the *Domain of Practice*. Finally, the *Domain of Consequence* entails the salient outcomes, which may include student learning outcomes and classroom interactions that emerge from a teacher's learning and implementation efforts.

For this study, we explored the interactions between three of the four domains. The two professional development experiences comprised the External Domain in this study. Considering the Personal Domain, teachers' epistemic orientations and knowledge of argumentation instruction served as the focal knowledge constructs explored. Finally, we explored shifts in students' scientific reasoning, representing the Domain of Consequence as a goal for enhancing productive science talk in the classroom to also provide students opportunities to enhance their reasoning abilities (Michaels & O'Connor, 2012; Kelly, 2014). Using the different professional development experiences as a point of comparison, we explored shifts in participating teachers' knowledge to determine any potential corollary shifts in their students' scientific reasoning abilities. The premise for this comparison concerns understanding if improving teacher knowledge around aspects of teaching involving reasoning (arguing from evidence and epistemic orientations) can contribute to students' learning to reason scientifically.

Methods

Data for this study are drawn from a year-long comparative professional development field study centered on fostering students' sensemaking about science through talk with a focus on the role of collaborative design in teacher learning and practice. The study is comprised of a treatment group that engaged in collaborative design, Learning through Collaborative Design (LCD), and a comparison group, Learning through Participation (LTP), who engaged in more traditional modes of PD that did not include collaborative design. Both groups engaged in a 36-hour, 6-day PD in the summer of 2021 led by the same four PD facilitators and in four sessions of PD during the 2021/2022 school year lead by three PD facilitators. During the school year LCD and LTP teachers taught four common focal argumentation lessons that serve as center points for the school year PD. A description of this PD can be found in Table 1. Thirteen teachers, seven from LCD and six from LTP, who participated in both the summer PD and the in-school PD (Table 2) and their students from two biology class section in which the teachers taught the focal lessons (N = 274) are the focus of this research. Table 3 provides demographic information for the teachers and their schools.

Data Sources & Analyses

Student Learning

The analyses for this proposal focus on the student learning gains in biological reasoning which occurred secondary to their teacher participating in one of the two PD interventions. Student learning was measured using the Assessment of Biological Reasoning (ABR, Schellinger et al., 2021; See Table 4). The ABR was administered at the start of the 2021/2022 school year (pre-test) and the end of the school year (post-test). See Table 5 for a timeline of data collection.

Student ABR pretest-posttest data were analyzed using paired sample t-tests, repeated measures ANOVA, and repeated measures ANCOVA. Paired samples t-tests were conducted to check for overall differences between the pretest scores and post-test scores. To test for differences in pretest-posttest changes between students of teachers who participated in the two PDs, a repeated measures ANOVA with time, PD type, and an interaction effect between time and PD type was run. This model aligned with research question 1.

Teacher Personal Domains

To answer research question 2, a repeated measures ANCOVA model was run, which added two additional covariates to the repeated measures ANOVA model: Epistemic Orientations towards Teaching Science (EOTS; Parks et al., 2018) and Pedagogical Content Knowledge of Argumentation (PCK of Argumentation; McNeill et al., 2016) levels after receiving the summer 2021 PD (which occurred before students received instruction, see Table 4). This model aligned with research question 2. Descriptions of the EOTS and PCK of Argumentation instruments can be found in Table 6.

Results

The first analysis of student data included a paired-samples t-test to test for significant differences in students' ABR scores. The results indicated that there were significant increases in ABR scores from pre to post. The average score difference from pre to post was .99 ($t=3.337$, $df= 273$, $p<.001$). This indicated an average increase of one point on ABR scores over the course of the school year. Next, we investigated if the gains on ABR scores were different between the two types of teacher PD using a repeated measures ANOVA. Pre and post ABR scores were included as a within-person factor, and PD type was included as a between person factor. The repeated measures ANOVA results indicated a significant interaction effect between PD types and ABR scores ($F(1, 272)= 12.325$, $p<.001$), indicating that the gains for students

showed different patterns based on their teacher's PD type. Pairwise comparisons showed that Students in LCD classrooms had significantly higher post-scores than students in LTP classrooms (mean difference = 1.341, p=.005, partial eta-squared = .043).
To parse out the relationship between student gains and teacher attitudes after the PD, we ran a repeated measures ANCOVA model, which added two additional covariates into the model discussed above: teachers' pre-school year EOTS scores and teachers' pre-school year PCK of Argumentation scores. The model included interaction terms between EOTS, PCK, PD type, and pre-post changes (labeled "time" in the table). Results from the F tests of these interaction effects are presented in Table 7.

The results showed significant interactions between time and PCK, and time and EOTS. However, once PCK and EOTS covariates were added to the model, the interaction of time and PD type was no longer statistically significant. This indicates that teachers' pre-school year PCK and EOTS had greater predictive power of student gains than PD type alone, and begins to provide evidence to the underlying mechanisms that may have contributed to student gains in biological reasoning. Based on the effect sizes (partial eta-squared in table 6), EOTS had a larger effect on student gains of the two significant interactions. The estimated marginal mean difference for the two PD groups was .978, this time with LTP students having the higher marginal mean, although the difference was not statistically significant.

Significance

Students across all participants' classrooms improved in their abilities to scientifically reason with biological concepts, but students in LCD teachers' classrooms evinced significant improvement compared to those in LTP classrooms. This outcome provides evidence that PD focused on helping teachers support students' productive science talk can ultimately help students with abilities that are consequential to their participation in a democratic society. Further, the analyses show that when teachers adapted and redesigned existing curricular resources, students showed greater improvement with scientific reasoning. We posit that the intentional collaborative design activities afforded teachers valuable opportunities to consider and incorporate students' ideas as intellectual resources (Miller et al., 2018) while also being attentive to the questioning approaches they used while implementing the designed activities (Murphy et al., 2018). That is not to say the teachers from the LTP experience did not consider students' ideas as intellectual resources. However, teachers intentionally synthesizing these elements while revising existing materials focused LCD participants during planning stages in ways that could heighten their awareness of those resources as they implemented the lessons.

Another interesting finding points toward the importance of supporting teachers' learning about the epistemic function of scientific practices, including argumentation (McNeill et al., 2016a). Teachers' understanding of how to teach through argumentation and the sophistication of their epistemological beliefs both showed to be predictive of enhanced student reasoning. As teachers continue to develop their personal epistemological knowledge and related instruction, they are more capable of supporting their students in developing proficiency with engaging in epistemic work, including reasoning with scientific concepts. The interaction between teachers' knowledge and beliefs and the learning opportunities students experience in their classrooms remain an essential site for empirical research. This study highlights that consequential research in this area must continue to explore the ways teachers bring together multiple bodies of knowledge, including epistemological expertise, to support meaningful science learning that leverages students' intellectual resources to enhance their reasoning abilities (Schwartz et al., in press; McNeill et al., 2016).

This material is based upon work supported by the National Science Foundation under **DRL #1720587**. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. *Horizon Research, Inc.*

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, *18*(8), 947-967.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Routledge.

Christodoulou, A., & Osborne, J. (2014). The science classroom as a site of epistemic talk: A case study of a teacher's attempts to teach science based on argument. *Journal of Research in Science Teaching*, *51*(10), 1275-1300.

Ford, M. J. (2015). Educational implications of choosing "practice" to describe science in the next generation science standards. *Science Education*.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American educational research journal*, *38*(4), 915-945.

Gomez, R. E., Kagan, S. L., & Fox, E. A. (2015). Professional development of the early childhood education teaching workforce in the United States: An overview. *Professional Development in Education*, *41*(2), 169-186.

González-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education*, *104*(6), 953-982.

Kelly, G.J. (2014). Discourse practices in science learning and teaching. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education*, volume 2, (pp. 321-336). Mahwah, NJ: Lawrence Erlbaum Associates.

Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education?. *Science education*, *101*(1), 8-31.

Kwakman, K. (2003). Factors affecting teachers' participation in professional learning activities. *Teaching and teacher education*, *19*(2), 149-170.

McNeill, K. L., Katsh-Singer, R., González-Howard, M., & Loper, S. (2016). Factors impacting teachers' argumentation instruction in their science classrooms. *International Journal of Science Education*, *38*(12), 2026-2046.

McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2016). Pedagogical content knowledge of argumentation: Using classroom contexts to assess high-quality PCK rather than pseudoargumentation. *Journal of Research in Science Teaching*, *53*(2), 261-290.

Michaels, S., & O'Connor, C. (2012). *Talk science primer*. Cambridge, MA: TERC.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching*, 55(7), 1053-1075.

Murphy, P. K., Greene, J. A., Allen, E., Baszczewski, S., Swearingen, A., Wei, L., & Butler, A. M. (2018). Fostering high school students' conceptual understanding and argumentation performance in science through Quality Talk discussions. *Science Education*, 102(6), 1239-1264.

National Academies of Sciences, Engineering, and Medicine. (2016). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: National Academies Press.

Park, S., Kite, V., Phillips, L., Suh, J. K., & Jung, J., Does Teachers' Epistemic Orientation and Epistemic Understanding Matter in Implementing Science Practices? *Annual International Conference of National Association for Research in Science Teaching*. Atlanta, GA, March 10-13, 2018.

Schellinger, J., Enderle, P. J., Roberts, K., Skrob-Martin, S., Rhemer, D., & Southerland, S. A. (2021). Describing the development of the Assessment of Biological Reasoning (ABR). *Education Sciences*, *11*(11), 669.

Schwartz, R., Lederman, J., & Enderle, P. (2023). Scientific inquiry literacy: The missing link on the continuum from science literacy to scientific literacy. In J. Lederman & D. Zeidler (Eds.) The handbook of research on science education (Vol. III). Routledge.

Southerland, S. A., Granger, E. M., Hughes, R., Enderle, P., Ke, F., Roseler, K., Saka, Y., & Tekkumru-Kisa, M. (2016). Essential Aspects of Science Teacher Professional Development: Making Research Participation Instructionally Effective. *AERA Open*. https://doi.org/10.1177/2332858416674200

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education*, *98*(3), 487-516.

Voogt, J., Laferriere, T., Breuleux, A., Itow, R. C., Hickey, D. T., & McKenney, S. (2015). Collaborative design as a form of professional development. *Instructional science*, *43*(2), 259-282.

Wilson, S. M. (2013). Professional development for science teachers. *Science*, *340*(6130), 310- 313.

Table 1. Description of LCD and LTP PD Commonalities and Differences

	LCD	LTP
	Summer PD	
Time	36 hours across 6 days	36 hours across 6 days
Focus	Teachers engaged in activities that position them in the role of a student and in the role of a pedagogical learner to consider how student experiences can be leveraged to support talk in science classrooms to help teachers refine their practice. These activities were structured to follow the characteristic of effective PD described by Authors (2016), Desimone (2009), Kwakman (2003), Wilson (2013), and Yoon and colleagues (2007) including positioning teachers to focus on biology content, engaging teachers in active, collaborative, and coherent (e.g., align with policy and practice) learning around this content through inquiring experiences modeled using ambitious teaching techniques by PD facilitators, and ensuring a sufficient duration including intensity and hours. Examples of these activities include engaging in argumentation activities as students including examining and analyzing data, developing arguments based on evidence to answer a guiding question, and engaging in round robin share outs to discuss claims before revising them based on these discussions. Teachers concluded these activities by considering the pedagogies that support student talk and learning. Further, teachers engaged in activities to explore and examine pedagogies and effective teaching strategies and to consider their application in their classroom contexts.	Teachers engaged in activities that position them in the role of a student and in the role of a pedagogical learner to consider how student experiences can be leveraged to support talk in science classrooms to help teachers refine their practice. These activities were structured to follow the characteristic of effective PD described by Authors (2016), Desimone (2009), Kwakman (2003), Wilson (2013), and Yoon and colleagues (2007) including positioning teachers to focus on biology content, engaging teachers in active, collaborative, and coherent (e.g., align with policy and practice) learning around this content through inquiring experiences modeled using ambitious teaching techniques by PD facilitators, and ensuring a sufficient duration including intensity and hours. Examples of these activities include engaging in argumentation activities as students including examining and analyzing data, developing arguments based on evidence to answer a guiding question, and engaging in round robin share outs to discuss claims before revising them based on these discussions. Teachers concluded these activities by considering the pedagogies that support student talk and learning. Furthers, teachers engaged in activities to explore and examine pedagogies and effective teaching strategies and to consider their application in their classroom contexts.
Characteristics	Teachers were positioned to work collaboratively with peers to examine, retrofit, and redesign components of lessons to support student talk. This work was scaffolded such that teachers engaged in collaboration in the latter half of the first four PD days and then they spent the majority of the last two PD days collaboratively designing the first focal lesson they would teach during the academic year.	Teachers engaged in nature of science activities focused on examining characteristics of scientific knowledge to support teachers' understanding of knowledge generated through scientific reasoning. This work was scaffolded such that teachers engaged in these activities during times that coincided with times when the LCD group would have spent collaboratively designing curriculum.
	In-School PD	

Time	Four cycles of a design, teach, and an analysis session occurred across the 2021/2022 school year. The first design session occurring during the summer PD.	Four PD sessions occurred across the 2021/2022 school year after the teachers taught the focal lesson.
Focus	Each session centered on supporting student talk in one of four focal areas including the role of anchoring phenomena, use of student ideas and reasoning, role of evidence, and using student ideas towards the end goal.	Each session centered on supporting student talk in one of four focal areas including the role of anchoring phenomena, use of student ideas and reasoning, role of evidence, and using student ideas towards the end goal.
Characteristics	Teachers were supported to collaboratively design focal lessons to support student talk centered on one of four focal areas of concentration. Teacher then taught the redesigned lesson before coming together to collaboratively analyze moments (video clips) of the lessons centered on the focal area. Analyze lessons concluded with time for teachers to collaboratively revise their lesson.	Teachers were supported to discuss focal lesson centered on one of four focal areas. The teachers discussed how their lesson supported student talk, how students engaged in the focal area of the session grounded in the examination of student artifacts (e.g., work products such as lab reports and Claim-Evidence-Reasoning posters), and what changes they might make in future iterations of the lesson.

Table 2. Teacher Demographics (All teachers are identified by pseudonyms)

Group	Teacher	Gender	Race/ Ethnicity	Years Teaching
LCD	Allison	Female	White	14
LCD	Amelia	Female	Hispanic	14
LCD	Claire	Female	White	5
LCD	Deborah	Female	White	14
LCD	Heather	Female	White	5
LCD	Noami	Female	White	9
LCD	Stone	Male	White	7
LTP	Charlotte	Female	White	11
LTP	Diego	Male	Hispanic	2
LTP	Kambrie	Female	White	4

LTP	Savannah	Female	White	7
LTP	Scarlett	Female	White	5
LTP	Theo	Male	White	3

Table 3. School Demographics

Group	Teacher	School	% White	% Black	% Hispanic	% Asian	% ELL	% of Students on free or reduced lunch	Total School Population
LCD	Allison*	6	18	29	46	3	19	83	1744
LCD	Amelia	28	45	7	38	5	10	36	2344
LCD	Claire	19	19	52	19	7	7	61	1676
LCD	Deborah	20	71	5	16	3	2	15	2706
LCD	Heather**	24	41	12	43	1	17	68	2425
LCD	Noami*	6	18	29	46	3	19	83	1744
LCD	Stone**	24	41	12	43	1	17	68	2425
LTP	Charlotte	2	35	46	11	4	2	81	1742
LTP	Diego	15	25	16	54	1	20	64	2655
LTP	Kambrie	17	11	7	77	2	34	81	2301
LTP	Savannah	27	47	14	23	7	7	40	1664
LTP	Scarlett	11	34	27	31	5	18	65	2072
LTP	Theo	3	38	23	32	2	9	64	1954

* and ** indicate teachers at the same school

Table 4. Measure of Student Learning

Instrument	Description
Assessment of Biological Reasoning (ABR; Authors, 2021)	A three-tiered, validated multiple-choice instrument (30-item with four answer choices) encompassing 10 core biological topic areas covered in US high school biology classrooms. The assessment measures three dimensions of scientific reasoning, including a conceptually oriented question comprising the primary object of reasoning, a proceduraylly oriented question that engages the student in developing scientific explanations for the scenarios grounding the question, and an epistemically oriented question exploring how a respondent uses the focal science concept to construct their preferred explanatory response.

Table 5. Timeline of Data Collection

	Pre Summer	2021 Summer PD	Pre School Year	2021/2022 In-school PD	Post
Teacher Data					
Epistemic Orientation towards Teaching Science (EOTS) survey	X		X		X
Pedagogical Content Knowledge of Argumentation (PCK)	X		X		X
Student Data					
Assessment of Biological Reasoning (ABR)			X		X

Table 6. Measures of Teacher's Personal Domains

Instrument	Description
Epistemic Orientation towards Teaching Science (EOTS; Park et al., 2018)	A 44 five-point Likert scale instrument, measures teachers' epistemological beliefs including the nature of knowledge and knowing in general, the nature of knowledge and knowing in science, the nature of learning, and the nature of teaching.
Pedagogical Content Knowledge of Argumentation (PCK of Argumentation; McNeill et al., 2016)	An instrument in which teachers read four vignettes and respond to three multiple-choice and one open-ended question related to each vignette, measures teachers' pedagogical content knowledge of the practice of argumentation. In the assessment, teachers evaluate students' use of high-quality evidence to justify claims (evidence), students' use of scientific ideas or principles to explain the link between their evidence and claim (reasoning), students' ability to build off of and critique each other's ideas (interactions), and students' ability to critique competing claims (competing claims).

Table 7. Repeated Measures ANCOVA Results

	F	Degrees of Freedom	Mean Square	Sig	Partial Eta Squared
Time	17.983	1	188.227	<.001	.080
Time*PCK	6.892	1	72.132	.009	.032
Time*EOTS	20.548	1	215.067	<.001	.091
Time*PD Type	1.987	1	20.797	.160	.010
Error		206	10.467		

*Partial Eta Squared represents the effect sizes for each main and interaction effect, with .01 considered a small effect, .06 considered a medium effect, and .14 considered large (Cohen, 1988).