# The Relationship between Teachers' STEM Beliefs and Enacted Instruction within an Intensive STEM Academy

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Conference Paper submitted to the American Educational Research Association Annual Research Conference 2020

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**Abstract**

The first purpose of this study is to identify profiles of practice over time for middle grades teachers within the context of an intensive professional development (PD) using latent class growth analysis (LCGA). The second purpose of this study is to understand how those profiles relate to teachers' beliefs and other factors based on teacher surveys and interviews. We collected multi-wave data on teachers' self-efficacy, perceived confidence in and importance of implementing STEM instructional strategies, and observational data. In addition, we conducted in-depth interviews with a subset of teachers. The LCGA suggested two profiles of practice, with one group of teachers who increased and one group who decreased slightly. The relationships between profiles of practice and teachers beliefs and PCK were not statistically significant. In order to understand the factors that explained differences between the two profiles, we examined qualitative interviews with two teachers. Teachers identified four common factors that influenced their implementation of STEM including their understanding of STEM, an interest in leadership, the school leadership, and student achievement.

# The Relationship between Teachers' STEM Beliefs and Enacted Instruction within an Intensive STEM Academy

Following STEM-focused professional development (PD), teachers often experience unanticipated challenges translating STEM practices to their specific contexts (Kelly, Gningue, & Qian, 2015). Teachers who believe in the importance of STEM and are more confident in their abilities tend to overcome those challenges more efficiently than other teachers (Allen, Webb, & Matthews, 2016). This study is situated within the STEM Academy for Science Teachers (STEM Academy hereafter), which is an intensive teacher PD designed to support teachers in enacting STEM. Within the STEM Academy, we define STEM instruction to include five components: (a) project-based learning (PBL) (Capraro, Capraro, & Morgan, 2013), (b) maker-based instruction (MBI) (Bevan, Gutwill, Petrich, & Wilkinson, 2014), (c) socio-emotional learning (SEL) including student collaboration and communication (Bryan, Moore, Johnson, & Roehrig, 2015), (d) scientific process standards (NRC, 2012; NGSS Lead States, 2013), and (e) science pedagogical content knowledge (Shulman, 1986; van Driel et al., 1998).

The STEM Academy includes 90 hours of summer coursework focused on STEM (e.g., PBL, MBI, and SEL connected to content and process standards). During each of up to three years of participation, teachers engage in up to seven feedback cycles annually and professional learning communities (PLC) at their school with a university instructional coach, who observes their instruction, provides individual feedback to the teacher, and facilitates the school PLC. Teachers have an opportunity to enroll in a master's program, for which they receive course credits as a part of the STEM Academy. Initially, for this paper, we examined the relationship between change across time in teachers' beliefs and enacted instruction using latent growth modeling. However, change in teachers' beliefs as measured by teacher surveys was negligible. Therefore, we revised the focus on the paper to focus on identifying profiles of practice based on teachers' enacted practice across time using a latent class growth analysis (LCGA). This analysis allowed us to group teachers empirically based on change across time in enacted practice. These profiles of practice, when linked with teacher surveys and in-depth qualitative interviews, support an understanding of which teacher beliefs and other factors promote (or inhibit) the implementation of STEM within classrooms. Given our small sample size, we present this evidence as exploratory.

Our research questions include:

1. Based on a latent class growth analysis (LCGA), what are the profiles of practice for teachers who participated in the STEM Academy for Science Teachers?
2. How does profile membership relate to quantitative survey measures of teachers' beliefs about STEM instruction (i.e., teachers' confidence in teaching STEM, perceived importance of teaching STEM, and self-efficacy for teaching science)?
3. How does profile membership relate to a survey of teachers' pedagogical content knowledge (PCK)?
4. Based on teacher interviews, what are other factors that promote (or inhibit) teachers' implementation of STEM for two teachers in different profiles?

## Methods

**Quantitative data collection.** We collected multi-wave measures of teachers' STEM beliefs coupled with classroom observations of their enacted instruction. Our sample included 39 middle school science teachers from a large, urban school district in a Southern state. The majority of teachers were female (73%), Black (54%), and did not have a master's degree (81%). Teachers had an average of six years of teaching experience. The data in this study were collected during the 2018-19 school year when one cohort of teachers was at the end of their second year of participation (n=11) and a second cohort of teachers was near the end of their first year of participation (n=28). This study includes quantitative measures of teachers' beliefs, PCK, and enacted STEM instruction. More specifically, we measured beliefs including:

- Science self-efficacy using the Science Teacher Efficacy Beliefs Inventory (Bleicher, 2010), and
- Confidence in and importance of STEM instruction using a researcher-developed tool called the STEM Perceptions, Practices, and Culture survey (STEM PPC), which was supported by confirmatory factor analysis.

We measured teachers' PCK using the Pedagogy of Science Teaching Test (POSTT) (Cobern et al., 2013). We measured STEM enacted instruction using the STEM Teacher Observation Protocol (STEM TOP), which was developed based on existing measures of STEM instruction and supported by multilevel exploratory factor analyses. Using the STEM TOP, calibrated university instructional coaches (n=5) conducted classroom observations of teachers' lessons.

**Quantitative analytic strategy.** We fit a series of LCGMs examining profile membership based on STEM TOP observations at four time points during the school year (i.e., beginning of the school year, mid-fall, mid-spring, end of the school year). These timepoints were selected because they corresponded with the timepoints for measures of teachers' beliefs. We measured PCK at the beginning and end of the school year only. As is typical with longitudinal data sets, our data set included some instances of teacher non-response, which we addressed using the robust maximum likelihood (MLR) estimator in M*plus*. For most teachers, data were available at each time point on all measures (i.e., 36 of 39 teachers had no missing data). The specification for the LCGM focused on teachers' enacted instructional practice because we were specifically interested in sorting teachers into groups based on classroom implementation of STEM across time. In addition, we focused on enacted instructional practice because these models are adequately powered (i.e., the number of estimated parameters did not exceed the number of participants), which was important given our small sample. We estimated a series of LCGMs specifying between 1 and 4 membership profiles. We set our fit criteria such that a lower AIC and BIC and higher classification entropy would indicate the best fitting model. We also specified that each group must include at least two teachers.

**Qualitative data collection.** A subset of teachers participated in one-hour semi-structured teacher interviews. We interviewed teachers who: (a) returned to participate in summer PD before the 2019-20 school year, and (b) completed all requested multi-wave surveys. We specified these criteria for teacher interviews because we were interested in examining individual teacher's change across time on the measures in relation to teacher's interview responses. One of three trained researchers conducted the interviews. In summer 2019, 21 of the 39 teachers returned for the third year of the STEM Academy.

During the summer PD in 2019, we interviewed 14 of 21 returning teachers who had completed all requested survey measures across the course of the STEM Academy.

**Qualitative data analysis.** For the purpose of this paper, we wanted to highlight the factors that contributed to promoting STEM instruction in teachers' classrooms. Therefore, we selected two teachers who had above average implementation of STEM at the end of the school year, but each belonged to a different profile of practice. We selected these teachers as cases because their implementation at the end of the school year suggested that they were more successful than average in implementing STEM instruction in their classrooms. At the same time, we were interested in further investigating these two cases because these teachers belonged to different profiles of practice based on the LCGM. To protect participant identities, we use pseudonyms instead of teachers' names and do not disclose teacher race/ethnicity or gender. Two researchers coded and analyzed interview transcripts using multiple case study analysis (Stake, 2006). The researchers used a priori codes, which focused on the components of the STEM Academy (e.g., MBI, PBL, SEL), teacher beliefs (e.g., confidence, importance), and other factors (e.g., PCK, student engagement, school leadership, teaching colleagues). The agreement rates between the two coders on the first interview ranged from 74% to 100%. Following a meeting to resolve discrepancies, agreement rates on the second interview ranged from 99% to 100%. Following coding, the first researcher summarized each interview by code and the second researcher reviewed summaries for accuracy. Subsequently, the first researcher compiled the summaries by code in an Excel document, summarizing responses by code across interviews. The first researcher generated a summary of emerging themes based on the cross-case analysis; the second researcher reviewed the Excel document and summary for accuracy.

## Results

**Based on a latent class growth analysis (LCGA), what are the profiles of practice for teachers who participated in the STEM Academy?** Based on the fit statistics in Table 1, we determined that the 2-profile solution demonstrated the best fit with our sample. This solution demonstrated the lowest AIC and BIC. The sample adjusted BIC was slightly lower for the 4-profile solution; however, one of the profiles for the 4-profile solution only included one teacher, which limits inferences. The 2-profile solution is the best fitting for this sample of teachers. If additional teachers were included, it is possible that additional profiles would emerge. However, our main goal for this empirical analysis was to empirically group teachers in such a way that we could analyze their qualitative teacher interviews and relationships to other measures. We determined that the 2-factor solution was adequate for grouping teachers for the purpose of subsequent analysis.

Table 1. *Overall Fit Statistics for LGCMs focused on Enacted Instruction*

| | | | | | | # (%) of Teachers | | | |
|---|---|---|---|---|---|---|---|---|---|
| # of profiles | # of free parameters | AIC | BIC | Sample-size adjusted BIC | Classification entropy | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 1 | 22 | 336.54 | 373.14 | 304.32 | 1.00 | 39 (100%) | | | |
| 2 | 27 | 320.19 | 365.11 | 280.65 | 0.97 | 30 (77%) | 9 (23%) | | |
| 3 | 32 | 334.73 | 387.97 | 287.87 | 0.96 | 10 (26%) | 2 (1%) | 27 (69%) | |
| 4 | 37 | 327.09 | 388.64 | 272.91 | 0.96 | 1 (0%) | 5 (12%) | 14 (36%) | 19 (49%) |

The STEM TOP measures two dimensions of STEM instruction: (a) integrated STEM instruction, and (b) management and discipline. Figure 1 shows the mean scores on these dimensions across time for Profile 1 teachers (blue; 30 teachers) and Profile 2 (yellow; 9 teachers). Based on coaches' observation of classroom instruction, Profile 1 teachers decreased slightly in their implementation of integrated STEM instruction during the 2018-19 school year; whereas, teachers in Profile 2 increased. Teachers in both profiles were relatively consistent across the school year in their management and discipline, with slight decreases for Profile 2 teachers. This suggests two profiles of practice; one group of teachers whose instructional practice did not change much with slight decreases in integrated STEM across the school year (i.e., Profile 1) and another group whose instructional practice increased slightly in integrated STEM, which may have resulted in teachers sacrificing some classroom control or management and discipline (i.e., Profile 2).

A two-way ANOVA indicated that the interaction between teachers' profile and timepoint on teachers' integrated STEM instruction as measured by the STEM TOP was statistically significant, $F(3, 107) = 10.34$, $p < .001$. This suggests that these two profiles differed in statistically meaningful ways in their implementation of integrated STEM instruction as measured by the STEM TOP. On the other hand, for teachers' management and discipline, the interaction between teachers' profile and timepoint was not statistically significant, suggest that these two profiles did not differ significantly in their management and discipline.

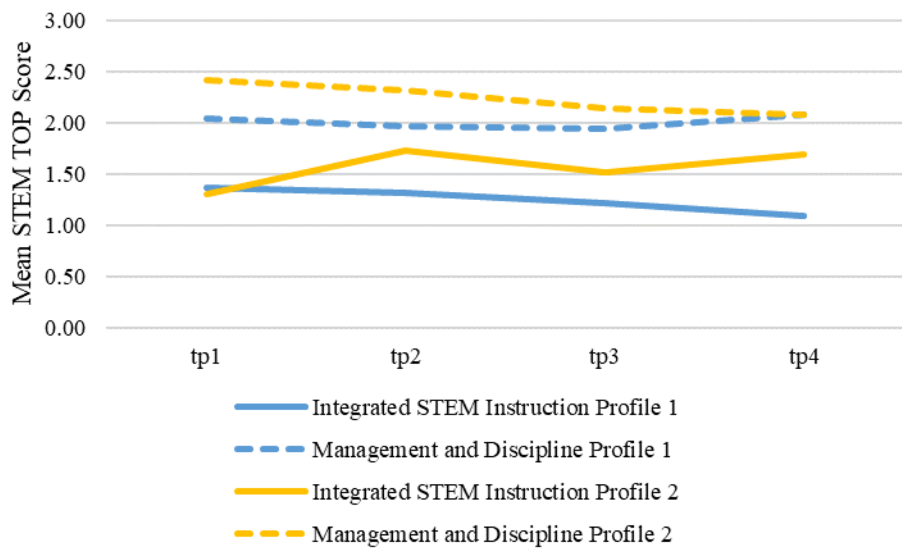


*Figure 1.* Teachers' Mean STEM TOP Scores Across Time by Profile

**How does profile membership relate to quantitative survey measures of teachers' beliefs about STEM instruction (i.e., teachers' confidence in teaching STEM, perceived importance of teaching STEM, and self-efficacy for teaching science)? How does profile membership relate to a survey of teachers' PCK?** We examined Profile 1 (blue) and Profile 2 (yellow) teachers' mean scores across time on measures of: (a) teacher self-efficacy for teaching science; (b) the importance of integrated STEM instruction; (c) teacher confidence for implementing STEM instruction; and (d) PCK. A two-way ANOVA indicated that interactions between the teachers' profile and timepoint on these measures were not statistically significant, suggesting that the two groups were similar in their beliefs and PCK. We did not observe relationships between survey measures and teachers' profile of practice, suggesting that teachers in the groups did not differ systematically in their beliefs or PCK. This is not surprising given that we observed negligible change across time in teachers' beliefs and PCK across time. We were interested in understanding differences between profiles based on other factors. As such, we sought to explain the variability in enacted practice across profiles through qualitative interviews. For the purpose of this paper, we investigated two teachers who had above average implementation at the end of the school year, but empirically belonged to different profiles based on their implementation of STEM.

**Based on teacher interviews, what are the factors that promote (or inhibit) teachers' implementation of STEM for two teachers in different profiles?** For the purpose of this paper, we focus on one Profile 1 teacher (Nia) and one Profile 2 teacher (Cadence). Figure 2 shows overall means across time based on the STEM TOP.

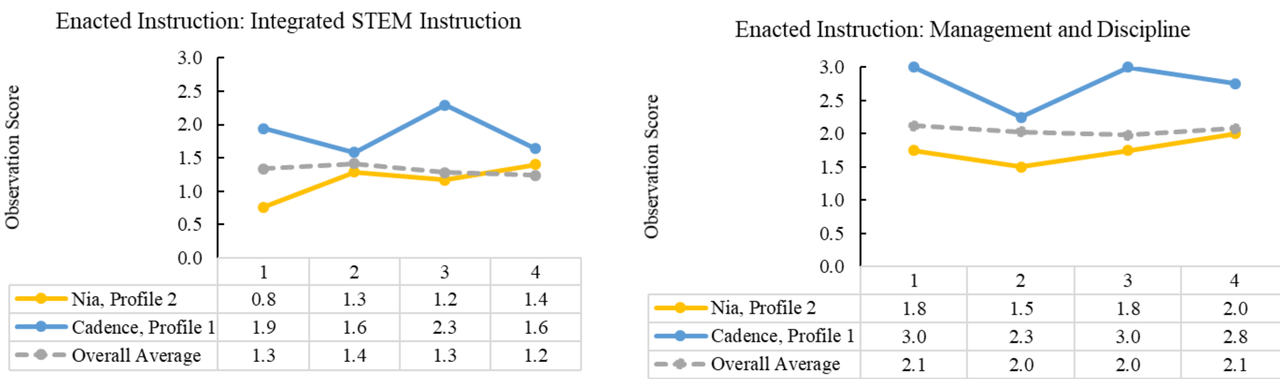


Figure 2.

Their change across time in enacted instruction demonstrated markedly different implementation across the course of school year. Cadence demonstrated consistently higher than average enacted instruction, but her enacted instruction decreased slightly near the end of the year; whereas, Nia demonstrated consistent increases across time in integrated STEM instruction. Nia demonstrated consistent growth across the school year in integrated STEM instruction; whereas, Cadence started the year with higher levels of implementation and subsequently decreased slightly. These teachers were similar in that they both had been involved in the STEM Academy for two years with similar cumulative teaching experience. In our qualitative analysis, we sought to identify factors that promoted integrated STEM instruction and understand how the two teachers' differed. Our findings indicated that both Nia and Cadence identified qualities related to four main factors that influenced their instruction across time. We describe these factors in this section.

***Teachers' deep understanding of STEM education.*** Both Nia and Cadence described a deep understanding of STEM education. They emphasized the importance of inter-disciplinary integration, effective teacher questioning, and promoting student agency within STEM education. Both teachers described examples of interdisciplinary integration. Examples of integration with mathematics were most advanced; whereas, connections with technology were the least advanced. The two teachers' descriptions of PBL and MBI differed in frequency and depth. Nia described four in-depth PBL units; whereas, Cadence described one MBI unit with less detail. Cadence emphasized student excitement when describing her MBI unit, saying, "[Students] had to build their own airplanes out of material like paperclips and different kinds of paper that they wanted and different things like that. So I was teaching force in motion, but they also are learning a component of that and it just made the kids excited. Each step that we were going through, they were excited to come back the next day." Nia described the use of questioning to promote student thinking. In the context of a plate tectonics lesson where students explored how objects could interact using racing cars, she said, "'Okay, what are some other ways that objects move, other than just towards each other? If they're going to contact each other, what's other ways they can hit each other?' [The students] were like, 'Oh, well maybe they could rub up against each other. Maybe they could, one could go under the other.' … Then I said, 'Okay, what does it look like if they don't hit each other?' I introduced that in the middle of the activity, after they had been interacting with the objects a little bit. They're like, 'Okay, well they're going opposite directions maybe, or just missing each other.'" Both teachers described an in-depth understanding of integrated STEM, but relative to Cadence, Nia's examples emphasized student thinking and teacher questioning more often and with greater depth.

***Interest in leadership.*** Both Nia and Cadence described an interest in pursuing leadership opportunities in education. Nia joined the STEM Academy because she was seeking additional leadership opportunities. Cadence was hesitant to join the STEM Academy because she wanted to pursue other leadership opportunities. Nia described taking on a leadership role at her school focused on inter-departmental collaboration and implementation of PBL. She said, "The math department was supposed to integrate more PBL stuff last year. They were like, 'Well, I don't know what I'm doing.' I was like, 'Well, I can send you this [PBL] calendar.' It just has a breakdown of what you should do each day. That helped me a lot like, 'Oh, okay. If I'm doing a three week unit and it's PBL, now I have a structure to know what

I should do each day.’ Okay, now I have some organizational tool in mind.” Cadence did not describe examples of her leadership at her school specific to PBL. Nia described supportive teaching colleagues saying, “Next year, we've already got a schema and all this stuff, and the projects we're going to do, and the materials we need. We're just going to try doing it that way and just see where it goes. We have to get better at this. We want as much practice as possible at doing this and this stuff, because that's more realistic and can apply better to real life.” This evidence suggests that the teachers were both interested in leadership opportunities, but the two teachers differed in that Nia described how she encouraged other teachers at her school to implement STEM and those teachers were supportive and collaborated to develop of a plan for the implementation of PBL.

***Leadership support.*** The two teachers had different experiences with school leadership. Nia stated that she did not experience many of the barriers other teachers may have had while implementing STEM. She said that her principal trusted her, which allowed her autonomy in her classroom. On the other hand, Cadence experienced a change in school leadership from the 2017-18 to the 2018-19 school year. The principal during her first year in the STEM Academy was “uplifting” and supportive of integrated STEM, which may have contributed to her higher scores at the beginning of the school year. However, she described the new principal as not engaged and “all test driven” which made implementing STEM challenging. She said, “[Administrators] don't want to come in my room and see the kids building things. … They want to see us … do test strategies. So that was a battle.”

***Connection between STEM and achievement.*** Neither of these teachers described a direct connection between integrated STEM instruction and student achievement. Both teachers described outcomes of STEM instruction related to other skills like connections across disciplines and student engagement. Nia said, “The importance of making connections is a lot more important than a test score. Everyone says they’re correlated, but sometimes they're not correlated.” She goes on to describe in-depth learning as more desirable than surface-level breadth of knowledge, which she said is measured on state tests. In general, neither teacher described specific connections between integrated STEM instruction and students' understanding of grade content standards as measured by traditional assessments such as standardized tests.

**Conclusion**

We observed evidence of two profiles of practice with the sample of teachers who participated in our study, one group of teachers who decreased slightly in their implementation of integrated STEM instruction (Profile 1) and one group who increased (Profile 2). These two profiles of practice differed significantly in their implementation of integrated STEM instruction across time, supporting that they differed in meaningful ways. A main purpose of this study was to understand how these profiles differed based on beliefs and other factors in order to understand what matters most in promoting implementation of integrated STEM through intensive PD. We did not observe evidence of statistically significant relationships between teachers' profile of practice and teachers' beliefs or PCK. This is likely due to the inadequate variability and negligible change that we observed across time on these survey measures. Teachers tended to rate themselves consistently high on these measures, with teachers in Profile 1 tending to rate themselves slightly higher than teachers in Profile 2, which may be evidence of reference bias (Egalite, Mills, & Greene, 2015). In general, these findings align with exiting work highlighting the difficulties with measuring teachers' beliefs quantitatively (Wyatt, 2012).

We examined qualitative interviews for two teachers who were more successful that average in implementing integrated STEM instruction, but belonged to different profiles of practice. We wanted to understand what factors contributed promoting integrated STEM instruction and better understand why they belonged to different profiles of practice. Cadence demonstrated higher implementation across the school year in her integrated STEM instruction, but with slight decreases across time; whereas, Nia consistently increased, but never scored higher than Cadence on integrated STEM instruction. Qualitative evidence suggests that Nia implemented PBL and MBI more often than Cadence and with more of an emphasis on student thinking and teacher questioning. By the end of the school year, Nia described herself as a leader at her school who was facilitating inter-departmental collaboration focused on STEM. She described her leadership as supportive and trusting of her instructional decision-making. Nia is = well positioned to continue to grow as a STEM teacher leader at her school. On the other hand, Cadence started out the year strong with higher implementation of integrated STEM instruction. Her scores on the STEM TOP suggest that she was able to incorporate integrated STEM instruction, but her interview at the end of the school year did not highlight in-depth examples of PBL or MBI. She described challenges related to differing expectations between her vision for instruction and that of school leadership. Cadence had a deep understanding of integrated STEM, but was not able fully implement this vision throughout the school year in the context of her school.

**Significance**

In general, these results illustrate the complexity in affecting teachers' STEM instruction even within the context of intensive STEM PD. Extant research suggests that teachers' instructional decisions are largely driven by the school vision and leadership (Camburn et al., 2003). Without the support of school leadership, STEM PD may not have the intended effects. In addition, we observed limited variability and negligible change across time as measured by surveys of teachers' beliefs and PCK. This might be due to issues in measurement of these constructs. Teachers may over-report their beliefs because of social desirability or reference bias. It is also possible that teachers' STEM beliefs and PCK were resistant to change. Gusky (1988) suggests that teachers' beliefs often do not change until teachers observe changes in student achievement as a result of their enacted practice.

We found it surprising that neither teacher emphasized the connection between the integrated STEM instruction and student achievement. Research demonstrating the connection between STEM interventions and student achievement is overall positive, with an average effect size of +0.21 (Lynch et al., 2019). However, an interesting similarity between these two teachers is that both Nia and Cadence did not identify a direct connection between STEM education and student achievement, which may partially explain why teachers beliefs were less apt to change. This suggests that STEM PD needs to be closely connected to teachers' grade-level content standards, emphasizing the relationship between student tasks and knowledge. Rigorous integrated STEM curricula connected to the content standards would be a significant contribution to the field.

**Next Steps**

The qualitative results of this study are limited to two teachers. Next steps will include additional qualitative analysis with eight teachers (i.e., four Profile 1 teachers and four Profile 2 teachers), which will allow for more in-depth qualitative results across multiple teachers. This work supports others who are interested in affecting change in teachers' enacted instruction and beliefs through intensive PD by identifying characteristics of the individual or the school that support or inhibit teachers' implementation of STEM.

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