JPR
Journal of Pedagogical Research

Research Article

The construction of systems thinking pedagogy during a professional development institute

Gretchen S. Goode¹ and Laurie MacGillivray²

¹University of Southern Mississippi, United States (ORCID: 0000-0002-8916-0195)
¹University of Memphis, United States (ORCID: 0000-0001-8962-2698)

The prevalence of systems thinking pedagogy is growing in classrooms because of its inclusion in the Next Generation Science Standards and its potential as a tool for addressing complex, global problems. While most of the research on systems thinking targets the ways students develop system thinking skills, this qualitative study explores teachers' construction of systems thinking as a pedagogy in a professional development context. With this paradigm-shifting pedagogy, teacher learning in professional development is a critical piece of understanding how the practice is taken up. Using social constructionism, discourse analysis, and systems theory, we conducted a holistic case study to analyze how teachers privileged language and ways of knowing during a professional development institute on systems thinking. We found that the teachers considered systems thinking as a catalyst for shifting their thinking, curriculum, and classroom dynamics; imperative to this shift was the implementation of systems mapping as the central activity of the pedagogy. Their model of systems thinking pedagogy respected both teachers and students as capable academics; additionally, it privileged a professional development culture of "becoming" in which the power of the collective was a point of leverage for teachers to disrupt what can be perceived as low expectations for their students and themselves as professionals.

Keywords: Systems thinking; Pedagogy; Professional development; Teacher discourse; Case study

"I can be dropped in any grade, any subject, and [systems thinking] is gonna be there for me in a way that…other tools and [professional developments haven't been]."
—Zia, elementary teacher

1. Introduction

The integration of systems thinking into education is on the rise in the United States, especially after its inclusion in the Next Generation Science Standards (NGSS Lead States, 2013). Both national and international researchers (Checkland, 1981; Curwen, et al., 2018), scientists (Capra & Luisi, 2014), and theorists (Cabrera & Cabrera, 2015; Senge et al., 2000) argue that systems thinking skils are necessary for addressing the complex problems the world faces—and will continue to face—in an ever-more-integrated world.

Systems thinking is an inherently transdisciplinary view of life that centers on relationships, patterns, connectedness, and context (Davis, et al., 2015). It is prevalent in sciences such as biology

---

How to cite: Goode, G. S. & MacGillivray, L. (2023). The construction of systems thinking pedagogy during a professional development institute. *Journal of Pedagogical Research, 7*(4), 275-302. https://doi.org/10.33902/JPR.202318879

and ecology (Capra & Luisi, 2014; Maturana & Varela, 1987), engineering (Checkland, 1994; Madni & Sievers, 2018), psychology and counseling (Chen et al., 2017) business (Checkland, 1994; Gharajedaghi, 2011), and, more recently, pedagogy (Cabrera & Colosi, 2009; Capra & Luisi, 2014; Curwen et al., 2018; Davis et al., 2015). Systems thinking has the potential to help us deal with global crises and protect the flourishing of life on Earth (Capra & Luisi, 2014; Curwen et al., 2018). For this paper, we drew primarily from educational systems theorists, including the Cabreras, Capra, Checkland, Davis, Luisi, Senge, and Sumara.

Exploring teacher learning processes will shed light on the values and perspectives that are foregrounded in this relatively new pedagogy. With the integration of systems thinking into classrooms, Chinn (2017) argues, "It is critical to develop means of preparing teachers to orchestrate learning adeptly with the innovative student learning environments that researchers are developing" because "there are challenges for teachers as they must learn new ideas…as well as facilitate students' learning" (p. 127). As systems thinking pedagogy is increasingly implemented and researched in classrooms (i.e., Curwen et al., 2018, 2022), there is an increasing need for studying teacher learning about this paradigm-shifting theory.

One method of investigating teacher learning processes is through analysis of teacher talk. By analyzing teacher talk, educational researchers can better understand teachers' beliefs, perceptions, social contexts, pedagogical concerns, and educational discourses (Kosko & Herbst, 2012; Liefshitz, 2015). This is important because teacher learning is "situated," involving "interactive systems that include individuals as participants, interacting with each another, as well as materials and representational systems" (Putnam & Borko, 2000, p. 4). Additionally, teacher learning is "multidimensional," and includes content knowledge, pedagogy knowledge, and classroom and student context (Leko et al., 2015, p. 39).

In this article, we analyze teachers' discourse in a professional development institute to expand the understanding of how systems thinking can be constructed (Berger & Luckman, 1966) as a distinct pedagogy.

2. Background

Studies on systems thinking in education often focus on student responses to systems thinking instruction, mostly within science classrooms (Ben-Zvi Assaraf & Orion, 2005, 2010; Danish et al., 2017; Hmelo-Silver et al., 2017). While they note the importance of teachers in the classroom (Chinn, 2017; Danish et al., 2017), most of this research targets students' systems thinking development; this study focuses instead on teachers' discourse about their own development in systems thinking instruction. Along these lines, we first explore the potential of research on teacher discourse as a method of analyzing teacher understandings. Next, we synthesize the strands of research on systems thinking in classroom instruction, highlighting the need for additional research on teacher understandings of systems thinking pedagogy.

2.1. Teacher Discourses

Discourse, or how language is used to enact social activities and identities (Gee, 1999), is a primary mechanism through which collaborative teacher learning occurs. Language has a vital role within the social construction of knowledge, as it both "produces and constructs our experiences" (Burr, 1995, p. 44) while we "communicate our intentions, our thoughts, our attitudes, and our values" (Soter & Conners, 2017, p. 45). Furthermore, we use words to influence and impact our own and others' behaviors, as well as to influence emotions and events (Soter & Conners, 2017). According to Gee (1999), discourse and its ensuing meaning is situation-based: it is actively constructed in various contexts and influenced by social groups. These meanings privilege certain languages and ways of knowing.

Because learning is both situated and social (Gee, 1999; Gergen, 1998; Putnam & Borko, 2000) and because "teacher talk provides a representation of the work of teaching," (Liefshitz, 2015, p. 10), there has been continued interest in studying discussions among teachers in various

professional development contexts (e.g. Kosko & Herbst, 2012; Liefshitz, 2015). Analysis of teacher talk during the exchange of ideas and critical reflection allows educational researchers to better understand "teachers' beliefs and values, …pedagogical and social aspects of teaching practice, and specific aspects of…teacher discourse" (Kosko & Herbst, 2012, p. 589). Accordingly, attending to the discourses in a systems thinking professional development can provide insight into the teachers' thoughts and values about systems thinking; additionally, it can provide understanding of how the discourses influence the teachers' emotions and pedagogical behaviors.

Within discourse, metaphor is especially salient to understanding teacher talk about the connections between teaching, learning, and systems thinking (Liefshitz, 2015). Metaphors are not only a matter of language, but a matter of thought, values, and reason (Lakoff, 1992; Lakoff & Johnson, 2008). A tool for understanding teaching and learning, metaphor analysis attends to "the experience of teaching, teacher identity, and teachers' professional knowledge" (Liefshitz, 2015, p. 16). Reflecting on the metaphors used in a professional development means "considering teacher talk about teaching as both the reflection and the making of teaching" (Liefshitz, 2015, p. 17). This is useful in this study because the institute's teachers, regardless of their experience with systems thinking, engaged in discourse about their developing pedagogical knowledge, making their talk both a creation of and a reflection of systems thinking pedagogy.

As teachers and other individuals talk, they are in the process of becoming (Davies & Harre, 2001). The fluidity of identity is reflected in our talk of the present and future (Gee, 1999). In our present being, we are creating/influencing the future. Rather than having static identities, the concept of becoming reflects that identity is in flux (Davies & Harré, 2001). This contrasts with the notion of roles perceived as static that imply a lack of becoming through discursive practices. Identity is created and recreated through discourse (Gee, 1999); this process can be conscious or subconscious. The metaphor of "becoming a teacher" has been used by researchers to analyze the complexities of learning to teach and to identify as a teacher (Ovens, et al., 2016).

2.2. Systems Thinking in the Classroom

Much of the research on systems thinking in education has focused on students' learning systems thinking content and skills in science classes (Ben-Zvi Assaraf & Orion, 2005, 2010; Danish et al., 2017; Hmelo-Silver et al., 2017). As new developments are made in integrating systems thinking into teaching (Ardell & Curwen, 2019; Cabrera & Cabrera, 2015), research can help us understand how teachers develop their own understandings of systems thinking and how their understandings of systems thinking influence their pedagogical decisions.

Within the classroom, systems thinking can be applied in multiple ways. Cabrera and Cabrera (2015) explain that teaching systems thinking should involve teaching four major skills: Distinctions, Systems, Relationships, and Perspectives (DSRP). These four skills require students to consider what distinguishes ideas or things within a system, the parts and wholes of a system, the relationships between the parts and wholes in the system, and the different perspectives from within or without a system (Cabrera & Cabrera, 2015). Such skills increase both creative and critical thinking (Cabrera & Colosi, 2009). Other educational theorists emphasize other systems thinking skills in the classroom: Capra & Luisi (2014) focus on identifying systemic problems and systemic solutions for real-world problems, while Davis et al. (2015) highlight the need to shift to a more expansive idea of education as inclusive of the human and not-human. Central to their theory of systemic sustainability education are the ideas of knowledge as a system, learning as a systemic transformation, and teaching as enlarging consciousness.

It is with these ideas of systems thinking education that we frame this study of one professional development that applies systems thinking to pedagogy. We differentiate between systems thinking as curriculum content and systems thinking as pedagogy: as content, systems thinking usually is taught in a single subject (usually science) as a unit; as pedagogy, it involves integrating systems thinking into the processes and procedures of teaching and learning across multiple subjects. We borrow from Tintiangco-Cubales' (2010) definition of pedagogy:

> Pedagogy is a philosophy of education informed by positionalities, ideologies, and standpoints (of both teacher and learner). It takes into account the critical relationships between the PURPOSE of education, the CONTEXT of education, the CONTENT of what is being taught, and the METHODS of how it is taught. It also includes (the IDENTITY of) who is being taught, who is teaching, [and] their relationship to each other… (as cited in Tintiangco-Cubales et al., 2010, p. viii-ix, emphasis in original).

This definition, hardly simplistic, emphasizes the constellations that come together to influence pedagogy.

Students learning within systems thinking classrooms have studied such wicked problems as modern-day slavery, drought, and pollution (Ardell & Curwen, 2019; Curwen, et al, 2018; Curwen, et al, 2020). Teachers and students generate systems thinking principles, or general "rules" of systems, as they discuss systems; they then apply and revise these generated principles as they further study interdependent systems, using them to address imbalances, inequalities, and injustices within social and environmental systems (Curwen et al., 2018; Curwen et al., 2019). Examples of systems principles include ideas such as *systems are made of wholes and their components* and *the components have dynamic relationships* (Ardell & Curwen, 2019; Ben-Zvi Assaraf & Orion, 2010, p. 541; Cabrera & Cabrera, 2015). Within these classrooms, researchers have found that students and teachers are able to develop a holistic worldview, reimagine a different world, and alter the existing educational discourse (Curwen et al., 2019).

The potential for students to make sense of the world through systems thinking signals the power of the teachers' role in this process (Ardell & Curwen, 2019; Curwen, et al, 2018; Curwen et al., 2019; Senge et al., 2000). However, while studies acknowledge the importance of teachers in constructing systems thinking lessons (Chinn, 2017; Danish et al., 2017; Wilson, 2013; Yoon et al., 2017), other researchers have found that teachers need to develop their own systems thinking skills (Hmelo-Silver et al., 2007; Yoon & Klopfer, 2006). Learning about systems can be challenging (Hmelo-Silver & Azevedo, 2006), and reaching expertise in complex systems thinking requires that teachers know not only the deep principles of their domain (in this case, the course content, teaching standards, and pedagogy) but also the deep principles of systems thinking (Hmelo-Silver et al., 2007). Both Chinn (2017) and Yoon et al. (2017) note a lack of research on teacher understandings of systems thinking as theory and pedagogy. Yoon et al. (2017) explain that while research studies have focused on designing learning environments for students, "only a handful have studied teacher understanding of complex systems" and systems instruction (p. 101). Chinn (2017) asserts, "it is vital for research on systems education to include a strong focus on preparing teachers" (p. 127). Developing systems thinking pedagogy requires a paradigm shift (Yoon et al., 2017) that involves developing altered views and discourses (Curwen et al., 2019).

To explore the complexity of teacher learning about systems thinking as called for above, we framed this qualitative study in social constructionism, discourse analysis, and general, educational systems theories. The interplay between the three frameworks provided the perspective for us as researchers to analyze the ways in which the teachers developed understandings of systems thinking theory, its place in their classrooms, and its relationship to their pedagogies. In this article, we explore how the facilitators and P-8 teacher attendees of a systems thinking professional development privileged certain languages and ways of knowing during systems thinking pedagogy construction.

To address this purpose, we posed the following research questions:

RQ 1) How do the facilitators and P-8 teacher attendees use discourse of and about systems thinking?

RQ 2) How do the facilitators and P-8 teacher attendees use discourse of and about teaching and learning?

3. Method

To address our research questions, we conducted a holistic case study of a four-day professional development on systems thinking. Case study methodology (Yin, 2018) was appropriate because it

invites in-depth investigation of a topic within its real-world context (Gee, 1999; Yin, 2018) by deconstructing and subsequently reconstructing various phenomena (Baxter & Jack, 2008). The "naturalistic social unit" (Dyson & Genishi, 2005, p. 2) of a professional development provided the opportunity to study the details of the subjects' constructed understandings of systems thinking pedagogy. We considered the elements that influenced the interpretations that teachers made about systems thinking (Dyson & Genishi, 2005).

Holistic case study methodology (Yin, 2018) allowed for the intense scrutiny of learning interactions within the situation, enabling us to attend to the construction of knowledge within the system of one professional development. We bound the case to one professional development because of the varying definitions and applications of systems thinking in educational research (Ardell & Curwen, 2019; Cabrera & Cabrera, 2015; Danish et al., 2017; Hmelo-Silver & Azevedo, 2006; Ison, 2008). It would be impossible to have a true picture of this unique systems thinking pedagogy construction without an in-depth consideration of the context in which the construction occurred (Baxter & Jack, 2008).

3.1. Setting and Data Collection

We collected data as members of a research team during the four-day summer professional development hosted at an independent school in Southern California. The research team consisted of three white researchers with a range of experience with systems thinking. As academics with K-12 teaching experience, our interests centered around the literacy events and practices; throughout the week, we found ourselves considering how we might use this pedagogy in our own classrooms with undergraduate and graduate students as well as how we might use systems thinking in our analysis.

After gaining IRB approval and the informed consent of all participants, the research team participated equally in collecting data through twenty semi-structured interviews (deMarrais, 2004) with the participants, ranging in length from three to five questions about their knowledge of systems thinking theory, their experiences with systems thinking in the classroom, and their learning during the professional development. Interviews ranged from twenty to forty-five minutes. We also collected our field notes (Emerson et al., 1995) from a combined sixty hours of observation of both formal and informal and whole group and small group sessions during the week. Finally, we used artifact collection (Yin, 2018), including personal research journals, handouts, and over 100 photos. We audio-recorded all observations and interviews. We rotated during the sessions, giving each member of the research team opportunities throughout the day to elaborate her field notes about observations and interviews. At least two members of the research team were present for all whole-group discussions, and one member observed during each breakout session. For this article, we drew from the entire pool of data.

A large portion of data collected from this institute was in the form of systems maps that were created and referred to during the institute. To create a systems map, teachers need a piece of butcher paper or a white board. Then, the teachers select an item or event familiar to them and their students (Goode et al., 2019) to map. Once teachers are ready, they pose a question to the students about the item. The teacher's primary role is to record the ideas on the map (Goode et al., 2019). In order to fully understand the context, we contrast system maps from other mapping procedures in detail here. Systems maps often look like webs: they begin from a central idea, moving outward to document the components and relationships (Cabrera & Cabrera, 2015). While systems maps are visually similar to other mapping techniques (Hyerle, 2008), they are distinct because the emphasis is on discovering complexities in a system. In contrast to other types of thinking maps (Stull & Mayer, 2007), the maps are organic because map components are not predetermined; instead, the components are decided during class discussion. Additionally, this method of systems mapping emphasizes revising the maps as students learn. Because maps are a student-teacher collaborative activity (Ardell & Curwen, 2019), teachers are integral for developing systems thinking in the classroom (Cabrera & Cabrera, 2015).

3.2. Participants

The institute was organized and run by a team of ten facilitators, and it was attended by seventeen teachers; all facilitators and attendees participated voluntarily in the study. All names used in this paper are pseudonyms. For clarity, we refer to "facilitators" as those who planned and led the institute, "attendees" as those paying to attend and "participants" as both groups together. This clarification was necessary because the facilitators talked and worked amidst the attendees whenever they were not presenting. This is an unusual practice, as typically presenters do not participate in the ongoing discourse of the session.

The institute's facilitation team was a collaboration of three teachers from the independent school, four teachers from a local public school, two consultants who had been working with the teachers for three years on implementing systems thinking pedagogy, and the institute director. The team had been meeting regularly for nine months to create the teachers-teaching-teachers professional development. The nine women and one man had between seven and thirty-five years of teaching experience, and they self-identified as racially and ethnically diverse: four white, one Hispanic, one Latina, one black, one Chinese-American, one multiracial, and one who chose to not self-identify. The director often started and ended the days, refocusing participants on group and personal goals. The facilitators took turns guiding whole and small group activities throughout the institute, and they presented examples of student work from their classrooms (see schedule in Figure 1).

Figure 1

The institute's four-day schedule included whole group and small group sessions

Time	Day One	Day Two	Day Three	Day Four
9:00	Introduction to conference	Both/and thinking practice	Teacher presentation on systems thinking and political action	Relating objects practice; Small group map 2
9:30	Introduction to systems thinking by the consultants	Systems thinking theory and research	Social justice guest speaker	Text-based reading protocol
11:00	Group systems map 1: Morning systems	Systems thinking for all learners	Breakout sessions	Keynote about beauty
12:00	Lunch	Lunch	Lunch	Lunch
1:00	Making observations and asking systems questions	Breakout sessions	Breakout sessions	Introduction of planning maps
2:15	Defining and generating systems principles	Breakout sessions	Using questioning; Group systems map 2: broken pencil; Small group map 1	Independent planning time; Planning for future contact
3:30	Group Reflection	Group reflection	Group reflection	Group reflection

The institute's seventeen attendees had varying experiences as teachers, with three participants just finishing their teacher education degrees, most with four to ten years of classroom teaching, and one teacher with more than thirty years in the classroom. Additionally, they all had varying familiarity with systems thinking pedagogy, ranging from no prior knowledge to four years of

classroom implementation. The attendees were also racially and ethnically diverse, including four Latinx, four white, three biracial, two black, and one Asian-American (three opted not to self-identify). There were fourteen women and three men.

3.3. Data Analysis

Gretchen performed much of the coding, with regular meetings and feedback from Laurie. To analyze the data, Gretchen began with an inductive thematic analysis method that "theorizes language as constitutive of meaning and meaning as social" (Braun & Clarke, 2006, p. 81). She used general educational systems thinking theories (i.e., Cabrera & Cabrera, 2015; Capra & Luisi, 2014; and Davis et al., 2015) as an analytical lens: she read/examined the data—fieldnotes, interview transcripts, session transcripts, and photos—and started making maps of the systems of discourse she saw. For example, in her first map of the data, she focused on mapping "language of systems thinking pedagogy," with concepts such as "wholes and parts" and "perspective"; her second map focused on "moments of systems thinking pedagogy learning," including terms such as "systems principles" and "mapping." In total, she created five separate maps; she started each map from scratch so she could look for the patterns in her own thinking by comparing the maps to one another and those collected in the study.

After five cycles of re-reading the data, focusing on transcripts of the sessions, and making maps, Gretchen kept returning to the ways the participants, through their discourse, constructed a pedagogy that valued shifts in thinking, systems mapping, teachers, students, and community action (see Appendix 1 for a full list of codes). With the focus on these values and with social constructionism and discourse analysis in mind, she began first-cycle coding of the data.

Gretchen used several first-cycle coding methods (Saldaña, 2009) to theoretically analyze the data thoroughly (Braun & Clarke, 2006). To begin, she used initial coding to grasp basic themes and issues (Charmaz, 2006). In this phase of coding, she read through the data to start breaking it into pieces, giving her a beginning point to start memo writing about the codes she was creating (Saldaña, 2009). Examples of initial coding include "systems," "continual movement," and "brokenness."

As she attended to the data during first-cycle coding, she also applied in vivo coding to capture and honor participant voices (Charmaz, 2006). As she read through the data, she "attuned" herself "to words and phrases that seemed to call for bolding, underlining, italicizing, highlighting, or vocal emphasis," as well as words and phrases that were repeated (Saldaña, 2009, p. 75). With a constructionist lens, the emphasis is on the shared language of the participants; focusing on in vivo coding helped her keep the participants' discourse central to the analysis. One example of this type of coding is "everything's connected," a phrase repeated by many participants throughout the week.

For the final stage of first-cycle coding, she went back through the data to complete descriptive coding (Miles & Huberman, 1994), working to identify the basic topic of data pieces using the prompt, "This comment talks about _____." The goal in this phase of coding was to develop the language of the data, with a focus on the topics and not the content of the data (Saldaña, 2009). Examples of this coding include "beginnings," "principles," and "teachers as learners."

While she was completing first-cycle coding, she regularly wrote analytic memos (Saldaña, 2009). These memos ranged from one sentence to more than a page, with the majority ranging in length from four to six sentences. After her first-cycle coding, she had more than 400 analytic memos. Some memos came spontaneously; others were scheduled times to write about the research questions after coding a block of data, such as a day's field notes, photos from a session, or an interview.

For the second cycle of coding, she used pattern coding and axial coding to reorganize and reanalyze the data to "develop a coherent synthesis" (Saldaña, 2009, p. 149). During pattern coding, she analyzed for patterns in the first cycle codes (Miles & Huberman, 1994); in axial coding (Charmaz, 2006), she explored how the coding categories related to each other in both properties

and dimensions (Saldaña, 2009). As she analyzed, she used Gee's (1999) explanations of situated meanings, including metaphors (Lakoff, 1992), to attend to the language and ways of knowing privilege in the teachers' discourse.

During this stage of coding, she again employed systems maps to capture the connections and relationships between the codes (Braun & Clarke, 2006), continually revising until she had several "network centers" (Davis et al., 2015); these centers became our findings. For example, she realized that her first cycle codes of "micro systems," "macro systems," "finding patterns," "personalizing systems," "social systems," and "finding gaps," as well as the metaphors of "tall," "wide," and "organic" learning were all related to breadth and depth in the curriculum; thus, "breadth of systems learning" and "depth of systems learning" became second-cycle codes that enveloped those first-cycle codes. Later, when she began mapping the second-cycle codes, she connected "breadth" and "depth" to the curriculum language. Finally, "depth" and "breadth" of curriculum" were included in the network center "expanding the content of education." Through this kind of analysis, she was able to understand the ways in which the teachers used discourse to create a cultural model (Gee, 1999) of systems thinking pedagogy. After writing the final codes as findings and sharing yet another draft with Laurie, we shared them with the third member of the research team to confirm that they were an accurate representation of the institute (Savin-Baden & Major, 2013).

4. Findings

Our first question, "How do the participants use discourse of and about systems thinking to construct systems thinking pedagogy?," called for a theoretical analysis (Braun & Clarke, 2006) of the teachers' situated meanings and actions surrounding their understandings of systems theory. To answer this, we first present the dynamic ways in which the teachers used metaphors of movement when talking of and about systems thinking; we then explore the main systems thinking tool used as a method of instruction—systems mapping—and how these maps transform the content of education. For our second question, "How do the participants use discourse of and about teaching and learning in their systems thinking pedagogy construction?," we focus our analysis on the other key components of pedagogy (Tintiangco-Cubales et al., 2010) that the participants (the facilitators and the attendees) emphasized in their discourse: context of education, views of students, teacher identity, and the purposes of education.

We circle back to previous findings often to make additional connections. Systems thinking pedagogy as constructed by the participants was an interactive, recursive process influenced by multiple perspectives. Ideas led back to other ideas, and often multiple ideas built on one another. This recursive element reflected systems thinking theory's exchange of linear thought in favor of interconnected, cyclical thinking (Cabrera & Cabrera, 2015; Davis et al., 2015).

The participants talked from multiple perspectives throughout the institute. At times, their perspective seemed clear as they talked "as learners" and/or "as teachers." Their complex voices were fluid; therefore, we move back and forth between these voices in our findings.

4.1. Systems Thinking Theory as Pedagogical Transformation: "I found my people!"

The institute facilitators used language that framed systems thinking as a catalyst for change in themselves and their classrooms. They described the process of learning about systems thinking as a "transformation"; this discourse developed during the first group session and was repeated throughout the four days. Most attendees integrated this metaphor into their own talk during the institute.

The discourse of movement permeated the conversations throughout the institute. Experienced teachers described feeling "pushed," or challenged, when they were learning how to apply systems thinking in their classrooms and "pushing back" when they felt the pedagogy was not working for them, in contrast to other professional development (Webster-Wright, 2009). Overall, though, the metaphors of movement were a positive contrast to the constraints of previous

teaching experiences. Denise, an experienced systems teacher, described the implementation as "freeing" and "liberating" as opposed to mapped and/or scripted curricula that emphasize "telling" over "teaching." Other attendees felt like the pedagogy allowed teachers to "take different routes" to achieve learning goals, meet standards, and prepare students for their end-of-year tests. In the words of Zia, an institute participant who had little understanding of systems thinking prior to the conference, "Systems thinking is a vehicle, and it's taking you somewhere." In contrast to learning how to implement a rigid curriculum, the teachers felt the possibilities in implementing systems thinking pedagogy.

Movement and transformation were described as a journey. The facilitators told the metaphorical "stories" of their systems thinking "journeys" in whole-groups and breakout sessions. As they told these stories, they talked about their "beginnings" and the learning "process," and they described their teaching as "evolving." They all described the beginnings as full of frustration and doubt, with a lack of clarity and a struggle to "get their heads around it [systems thinking]." But these feelings became more complicated with time. With a growing understanding of systems thinking, the plots were filled with recursive feelings of both frustration and "hope." As the stories were continually "developing," the presenters described themselves as "always learning" and "changing" as they began to appreciate the effects systems thinking had on student learning and community involvement. The participants deviated from the traditional "story" metaphor, however, by not telling an end to their stories; instead, they looked toward the future, noting that even with years of practice they were "learning still." One of the consultants explained that she thought "you can never know all of [systems thinking]." Thus, even the experienced teachers spoke as if they were in a state of transformation as systems thinking teachers. The participants referenced learning from each other. It was not simply the act of telling one's story, but also being in a community in which stories were valued and exchanged. Listening was integral to the evolution.

Importantly, the facilitators not only reflected on the transformation of their teaching in the past but also, as mentioned, on the powerful impact of the institute. The facilitators were participants in the institute, sitting among the attendees, working with the small groups, and joining other breakout sessions. During the last day of the institute, many of the ten presenters shared how they had changed during the four days after hearing the ideas, actions, explanations, and language of the other presenters. Like the attendees, they talked about re-assessing and adjusting lessons for the upcoming school year because of their learning during the week. Integral to the planning of the institute was the expectation for further support of the attendees: each member of the team made plans with attendees to form mentoring relationships, which would involve ongoing communication, classroom visits, and another day of professional development in the fall. Pedagogy as a transitional process was critical to the institute.

4.2. Transforming the Methods of Teaching: "Everything is connected."

The participants targeted two key elements of systems thinking that transformed their pedagogy: mapping as a method of instruction and systems principles as a key piece of content of education (Tintiangco-Cubales et al., 2010). These activities were open-ended and thus required a growth mindset.

Systems maps were the dominant vehicle for learning during the conference (for an example of a systems map, see Figure 2). The systems maps were distinct from traditional curriculum maps (a phrase not used at the institute) in two significant ways: first, they are created with the learners; second, they capture on-going conceptual understanding.

Throughout the institute, systems mapping provided a way of showing that "everything is connected." Participants described systems maps as an "interaction on paper" and as a visual of what learners "do know" instead of what they "should" know. During the mapping, a facilitator took on the role of teacher, posing open-ended questions to prompt a group's discussion about the system of study, such as "What other parts does that have?" The map facilitator focused on

listening to the responses from the participants, then guided the participants into naming new systems components and addressing connections within the system. After the participants mapped a system, the map became a prompt for reflecting on and discussing the systems principles that emerged from the map. Beatriz, a consultant, described the significant connection between the maps and the principles: "The principles are the syllabus; [the] maps are the curriculum." Within this pedagogy, an understanding of systems thinking principles is the main goal; systems maps are the materials used to build these understandings.

In the classroom, the facilitators explained, the map became a guide for deciding topics for further study. The institute facilitators both recommended and demonstrated leaving systems maps on the walls for learners to refer to, add to, and revise as they learned more about both the system and the systems principles, in a process of recursive learning. The systems mapping process sparked positive reactions in some participants who connected it to discovery: both Zia and Rachel compared it to the methods of ancient humans who created and revised maps of the "stars," the "seas," and the "human body" as they explored and became "experts" in their fields.

The idea of mapping during the school year, with new directions, topics, and questions arising from student discussions, was not accepted immediately by all the teachers. Tension arose as some teachers questioned the feasibility of "not knowing where [the curriculum] was going" because it was supposed to "be as open-ended as possible" and this could conflict with their responsibility to teach specific content. The teachers shared the pressures they felt with the need to "get somewhere" specific in their lessons, whether that "somewhere" was "the end of year test," "the standards," or "life skills." Experienced teachers offered some suggestions. Stacy tried to ease their concerns by explaining that she had the same feeling when she first saw the mapping method demonstrated, but that as she gained experience in systems thinking, the "standards and objectives across subjects [were] woven into systems thinking" naturally. Adriana described having the "standards checklist in [her] head" so she could find places to teach them during mapping. Carmela presented a breakout session on standardized writing assessment and systems thinking, describing how she used the topics of the yearly assessments as systems she taught in her classroom. Jane, one of the consultants, briefly mentioned that the use of novels as evidence to prove or disprove systems principles naturally addressed a Common Core standard.

While some participants seemed to accept these suggestions, one teacher, Mark, continued to question the mapping method, wanting more direct examples of meeting specific standards using systems maps. Mark had implemented some systems mapping in his classroom the previous year, and he was unconvinced that he should use it with (or instead of) the more traditional forms of instruction, like direct instruction and memorization, that he preferred. Overall, the metaphorical shift toward open-ended mapping as a curricular guide was a shift that made some teachers uncomfortable.

Figure 2
The map created during the first whole-group mapping session on morning routines
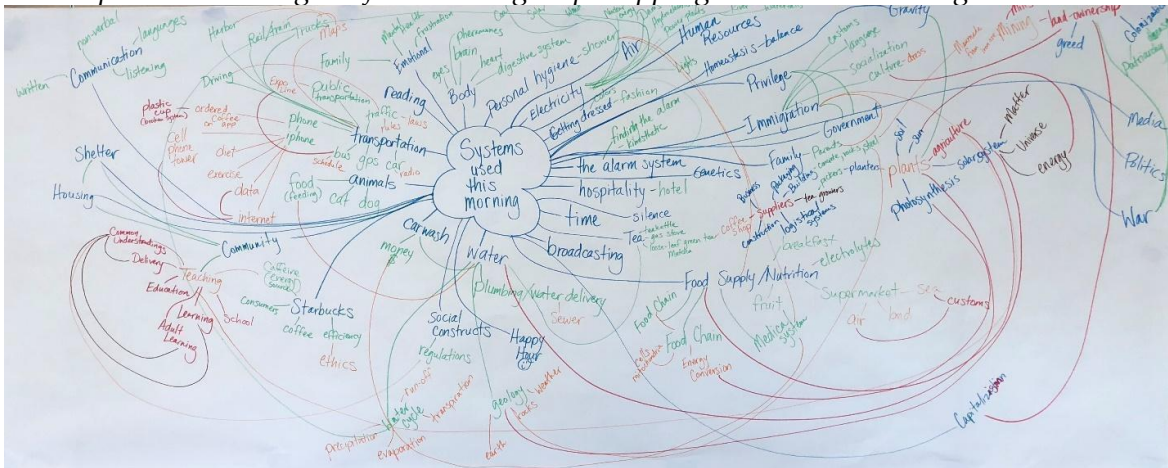
4.3. Expanding the Content of Education: "Learning is bigger and taller and deeper."

Systems thinking was also presented as a catalyst for integrating curriculum in deep and broad ways, with learning applied repeatedly in multiple situations (Bogard et al., 2018). Presenters asserted that several characteristics of mapping led to increased breadth and depth in classroom content.

4.3.1. Using maps as a pre-assessment

Additionally, the discourse during mapping expanded the maps from familiar content into unfamiliar content. To introduce systems, facilitators suggested starting with a system with which students are familiar (such as the "naming system": having students talk about how and why they were named). Using systems that were personal and well-known provided a starting point for understanding systems. Presenters described "slowing [the learners] down" when the map-making moved into less familiar material, and facilitators modeled slowing down in the institute's mapping sessions. For example, the broken pencil map moved quickly until someone mentioned "logging." When Beatriz, the consultant, asked for more information about logging, the conversation quieted. One participant admitted, "I don't understand the assembly line" for how trees became pencils. Beatriz responded, "Okay, let's go" and began acting out logging production, demonstrating how to prompt students instead of telling them. The map grew in depth surrounding the more distant (to this group of learners) topic of logging. Presenters explained that these areas of the map can indicate places for future learning.

4.3.2. Using maps to increase the breadth of curriculum

Maps often included a range of topics in contrast to narrow curriculum. A group map that centered on a broken pencil quickly branched out toward ideas like factory workers, transportation, and health care. Institute presenters further demonstrated how they used this in their classrooms. For example, Carmela described centering one of her first-grade units on the ocean; topics included ocean animals, environmental pollution, and water conservation. Lessons for these topics integrated science lessons on animal habitats, ecology lessons on the impacts of pollution, and writing lessons on informative paragraphs; the integration of multiple subjects provided depth to the developing curriculum. Carmela asserted, and other facilitators agreed, that curriculum integration happened naturally as learners found connections among the system components that exploded across traditional subject boundaries.

4.3.3. Using maps to add depth to the curriculum

The fluid movement between micro and macro systems was another map characteristic that added to the complexity of the discussions. "Systems Principles" was the term the experienced teachers used to describe the patterns that emerged across systems maps; they were themes that applied to most, if not, all systems (see Figure 3). The facilitators shared that the lists of principles their students produce are similar to this list, though the sophistication of the vocabulary and concepts varies depending on the age of the students.

Whether starting maps with a broken pencil or a toy truck, discussions integrated global and local systems. For example, during the first group mapping session on the morning routine system (Figure 2), local details such as using   an app to order my coffee" were included as well as global ideas like environmental protection (because pre-ordered coffee is not filled in reusable containers). Allowing discussion to take its natural path led to, as one participant noted,   learning [that] is bigger and taller and deeper."

Figure 3
The systems principles generated by attendees after a group mapping session
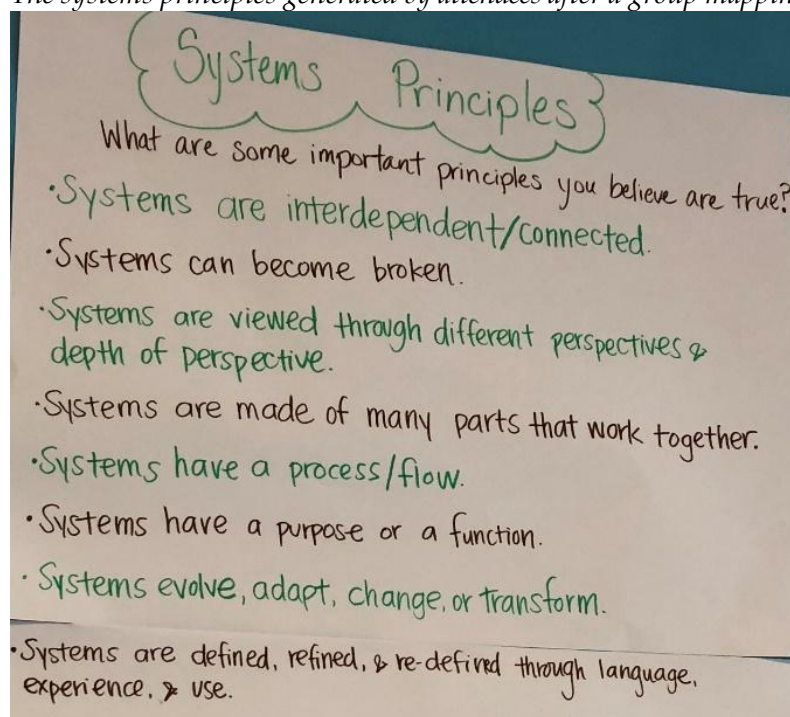
3.3.4. Using maps to compare and contrast across time

A final characteristic of the maps was increased learning came in finding patterns across time. The facilitators explained that systems maps can connect past, present, and future. The broken pencil map illustrated the potential for these connections. When discussing the production of the pencil, someone suggested factory workers. Another participant, David, jumped in, questioning whether pencil factories still need many workers or if the assembly line is fully automated now; debate followed about the history and future of factory workers. Facilitators gave more examples of incorporating history with units they had taught in their classrooms, including making connections between the political environment of the 1950's and current American politics. Facilitators stressed that making connections across time provided more depth to the curriculum.

3.3.5. Tensions with mapping

"Teachers wondered how to manage classroom time when integrating a curriculum that centers on student discussions. Maddie, one of the attendees, expressed that she felt   we had enough time here" to do systems maps, but she was not certain about classrooms where there is   pressure…to get to the end goal." However, the experienced teachers asserted the importance of using classroom time for students to   discover" knowledge, to   think and discuss" as a class, and to have   a time in the day when the class can be one."

Charlotte explained that some students struggled with changing the structure of class time, but even the ones who   wanted to stay on schedule" adapted to the less   regimented" time when they saw   important things being talked about." Prioritizing systems mapping was a use of class time that several teachers described as urgent. Danita impressed on the group,   The time to act is now." Denise agreed, saying   don t postpone." Abigail, one of the systems thinking researchers attending, urged that students already   deal with real problems now" and   are participating in democracy right now." She concluded with,   We don t get lifelong learners who wait for the clock to tick twenty-one years old."

Additionally, the depth of discussion about systems principles led to perceived tension among the participants at times. Debate about whether a chair or lint could be considered systems had teachers offering multiple ideas on both sides of the question, and no final decision was concluded.

Some teachers strongly believed that students needed to be able to recognize things that were not systems, while others felt thinking about systems was more important. However, even without consensus, the discussion prompted deep thinking and rich communication about systems principles.

In the end, implementing systems thinking pedagogy required a change in managing classroom time to provide learners with discussions that led to meaningful, integrated curriculum. The tensions present in the attendees 'discourse show the complexities of adopting a new pedagogy that does not align with the status quo of current classroom management that focuses often on covering standards and finishing the textbooks.

4.4. Enlarging the Context of Education: "We are connected to the world."

In addition to the emphasis on mapping and systems principles, the participants' discourse positioned systems thinking as a catalyst for developing a pedagogy that connects classrooms to the community and environment, attends to teacher needs, capitalizes on the strengths of students, and refocuses the purposes of education.

4.4.1. Connecting classrooms to the natural world

The discourse at the institute focused on the importance of enacting a pedagogy that integrated the world inside and outside of the classroom by providing wide applications of systems theory. The teachers at the institute connected the classroom to nature, seeing the world as a place where systems learning was abundant. Participants gave suggestions of systems units centered on the natural world, such as forests, flowers, oceans, and insects. They talked of the systems thinking classroom being "a part of" and "connected to" the natural world. The consultants shared the story of starting their very first systems lesson with a local ecosystem. Specifically, Beatriz used gardens as the introductory lesson to systems when she began her work as a consultant at the independent school. Stacy recommended "bringing [the] outside world in" and "taking the kids outside" often to "show [them] how beautiful the world is." The participants responded to her words, and many of them planned to start their systems maps with nature. At the conclusion of the institute, the participants decided that "we are connected to the world" was one of the critical principles of systems thinking that emerged from the group discussions because it is the basis of systems thinking theory and the motivation for taking environmental action.

4.4.2. Connecting classrooms to the local community

Learning from the local community was another element from outside the classroom that teachers experienced in systems thinking included in their systems thinking curriculum. Adriana and David recommended taking a "community walk" and mapping the students 'observations. After learning about systems, Rachel had adjusted her curriculum to have students create neighborhood photo-journals as part of a citywide study of immigration. The participants also wanted their students to know that they are members of their communities. Maya and Ginger described students studying the "systems broken in the community" so the students could "find their place in fixing" it. Multiple teachers recommended field trips so students could learn about and be active in the world. After the field trips, they explained, students revisited the systems maps and principles to discuss what they had observed and make revisions.

4.4.3. Connecting classrooms to families

Many of the experienced teachers also included parents in systems thinking pedagogy. Both Ginger and Jane advised informing parents about systems thinking early in the year. Jane specifically recommended assigning homework having the students write about the systems principles after the first systems map to "serve as a way to share with the parents." The new-to-teaching participants embraced the inclusion of parents and asked for more ways to "bring parents into the mix." Stacy shared that she had "parents send photos of systems maps at home." Carmela definitely recommended "informing parents" of units of study because "students will act on what

they are learning at home," such as the student who kept turning off the water "to conserve it" when his mother was trying to get hot water out of the faucet for washing the dishes. Denise warned that she had experienced "push back" from some parents because systems thinking was "not their school experience," and Stacy agreed, sharing that "at first it gave me anxiety [when] the parents were asking about the maps." However, she also had parents give positive feedback after seeing their students 'practice systems thinking at home. Notably, studying systems can spur discussions at home, as Ginger found out when a parent thanked her for talking to her students about refugees during a system map on a book the class had read together because the parent did not know how to start that discussion at home.

4.4.4. Creating visual representations on the classroom walls

As teachers brought the outside in and took students out into the world, the classroom walls, instead of being a simple boundary, became a more permeable space for displaying systems learning. The teachers talked of turning the walls of the classroom into the "curriculum," with the systems maps and principles posted as "living documents" with which to engage. Stacy recommended that teachers "put everything on the wall," and Adriana explained that "labelling the walls" is "important for English language learners." The ability to "read the walls" with the "classroom as curriculum" de-centered the teacher as the main source of learning. In systems thinking classrooms, Jane, the consultant, professed, "I learn from teachers, from children, from the room." Significantly, during the institute itself, the walls became covered with butcher paper showing systems maps, systems principles, participant goals, and open-ended question stems (Figure 4). It was an immersive experience, just as they proposed systems classrooms should be. There was no designated space from which to teach; speakers moved to different learning documents depending on the topic, using the whole space as a learning environment. This mission is an example of the way pedagogical approaches and strategies for the classroom were modeled throughout their time at the institute.

Figure 4

One of five sets of question stems posted on the institute walls; many such learning artifacts covered the walls, representing the connections between classroom learning and the real world
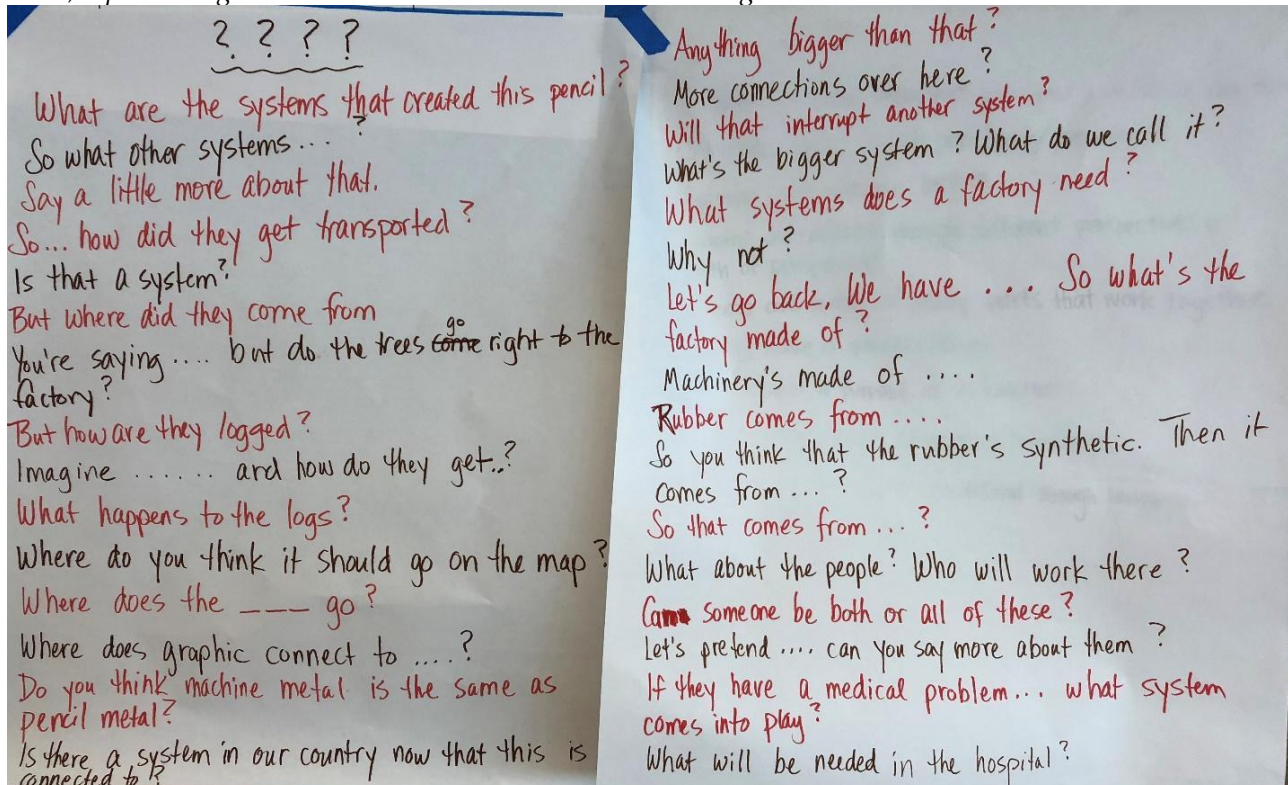
4.5. Revisioning Ideas of Who is Being Taught: "They are natural systems thinkers."

Another transformation of pedagogy that was reflected in the participants 'discourse during the institute was understanding the identity of students as complex beings (Tintiangco-Cubales et al., 2010). Both facilitators and attendees shared an esteem of students.

4.5.1. Highly knowledgeable students

Importantly, the discourse established students as already highly knowledgeable. Stacy nurtured this idea within the institute, reflecting on her first experience with a systems map, when she was astonished that the students "knew so much [that] I didn't know they knew." The participants also spoke of how their students knew about themselves and were aware of their learning. Adriana emphasized that she had seen her third and fourth grade students "get very metacognitive" when thinking with systems, explaining their thoughts well. Because students have knowledge and are aware of their own knowledge, they can be a participant in deciding what to study; they can be "active in writing the curriculum," according to Stacy.

According to the participants, students are not "vessels to be filled," as Rachel explained, but "natural" systems thinkers who have their own wealth of knowledge to contribute. Participants suggested that students in systems thinking classrooms "have the power to ask why" because their "curious nature" has not been "beaten out of them." Beatriz described students as having a "natural ability…to understand deeply" because "children have always been systems thinkers." David noted that even his kindergarten students "easily" understood that wholes are bigger than their parts, which is a systems thinking principle. Systems thinking pedagogy includes an esteem for students to encourage their "natural" abilities by using their interests and their strengths.

4.5.2. Students as activists

In this pedagogy, students not only had the ability to use their interests and strengths to change the curriculum, but also the power to make the world a better place to live. Both Carmela and Ginger described students as "little activists," with Ginger claiming, "Students want to take action." Both Danita and Rosie posited students as good "citizens" who can put systems thinking skills to work in their local communities. Systems thinking pedagogy was one way of helping students have the "esteem" and "confidence" to act.

Specifically, participants asserted that implementing the pedagogy had the potential to "empower" students to learn and teach others about their own needs. Adriana, who teaches students who are hearing-impaired, related that her students "wanted to be experts at the hearing system." Some of her students shared that they did not understand what was "broken" with their own hearing systems; several did not know how their parents first realized that their hearing was impaired. These students gained "the tools and words to talk and share" with others, including future teachers, about their needs; they became self-advocates, seeing their special needs as something in which they could be an "expert."

4.5.3. Concerns about students leading

While talk centered on giving students the opportunity to select topics and guide the learning, there were differing opinions about flexibility in the curriculum. Notably, many teachers preferred map-making strategies that kept them in control of the activity: they described asking the questions, selecting which ideas to write on the map, and where to place ideas on the maps. The map scribe (almost always the teacher) during the first group mapping session modeled having this kind of control as she recorded some responses while other comments were seemingly ignored.

However, on the afternoon of the third day, Stacy modeled a different way of making maps that shared the control, asking learners where they wanted their responses on the map. She explained, "I always ask where they [the students] want it [their response]." In the debriefing that followed, several experienced teachers commented that they had not previously included such a student-

centered strategy in map-making, and several teachers began implementing the method in the small group map-making that followed. Interestingly, while some teachers were initially hesitant, by the end of the institute many were embracing methods that purposefully give students more decisions. The teachers were willing to "give up control" and the "confidence" that comes with being in control to trust students with more power during classroom discussions.

Overall, the language of systems thinking pedagogy established students as more than just learners, but as natural systems thinkers, activists, and experts. Just as the facilitators talked about teachers having passions, so they talked about "making room for students 'passion"; the participants agreed that passion—both theirs and their students—should be a part of learning. The new-to-systems teachers noticed that the experienced teachers "found the students 'interests" by using the pedagogy, giving them the ability to "go where the students 'passion is." This approach to teaching placed students as important in the classroom discussions and gave teachers, according to Stacy, the ability "to see where [the students'] hearts are at." This humanizing language is a catalyst to positioning students as capable, strong, and empathetic. In these ways, students ' identities are esteemed as a powerful part of systems thinking pedagogy (Tintiangco-Cubales et al., 2010).

4.6. Repositioning ideas of who is teaching: 'Our brains are eager"

A fifth pedagogical piece that was developed through the participants 'discourse was the development of an understanding of the identity of the teacher (Tintiangco-Cubales et al., 2010) within systems thinking classrooms. Throughout the institute, the participants 'discourse reflected the identity of a teacher as both a teacher and a learner with physical, emotional, and intellectual needs. Systems thinking views a person as a system; for the whole person to perform their best, the needs of each system component must be met (Capra & Luisi, 2014). This perspective motivated the facilitators to consider all the needs of institute attendees. The facilitators purposefully designed parts of the institute to model this aspect of systems thinking theory as they simultaneously taught about the theory. One way they modeled systems thinking pedagogy was in the way they designed the professional development to both welcome and address the whole teacher-learner. The facilitators planned to address participants' needs as a part of preparing for the intellectual work.

4.6.1. Intellectual support for teachers

The facilitators considered how to support the attendees as teachers and learners. The facilitators regarded the attendees as intellectuals who could decide what topics would be interesting in their classrooms. Unlike a prescribed curriculum, the teachers were encouraged to bring their interests and expertise into their classroom curriculum (MacGillivray et al., 2004). The facilitators all selected what topics they would teach within the institute, and they all described bringing their interests into their own classrooms. Charlotte advised that the best way to start with systems thinking is to "pick an area of interest and go for it." Another experienced systems teacher attending the conference, Denise, explained that she used parts of history she found interesting, such as the Gold Rush, to make connections between historical issues and current events. Maya, one of the presenters, described using her favorite childhood books to read to her students and "talk about the systems inherent in the book." In these ways, systems thinking pedagogy included teachers 'individual interests as a positive instead of something to avoid in the name of professionalism and standardized education. The notion of separating the curriculum from teacher interests was actively dismantled.

At the same time, teachers were also seen as theoretical learners. Stacy, a facilitator, explained that deducing systems principles from systems maps was "theorizing," and the facilitators trusted that the teachers could do this kind of theorizing quickly. In fact, the act of theorizing was how the consultants taught the theory systems thinking: they avoided direct instruction, instead using questioning techniques to prompt the participants to look for patterns and principles within the systems maps. Ironically, one of the guest facilitators apologized for "talking about theories" in

one of the sessions when multiple teachers had already voiced their desire for more theoretical grounding. Zia expressed, "I see theory behind every action." Mark added "I can't teach…without theory." The attendees 'discourse positioned themselves as desiring theory in addition to practical application. When some teachers voiced their desire to understand the theory thoroughly before they implemented the pedagogy, the facilitators emphasized that the teachers did not need to learn everything about the theory beforehand. In fact, systems thinking is so complex, according to Beatriz, that "you are never going to know all of it." Beatriz and Jane, in talking about their first year of co-teaching systems thinking, described themselves as being "just a couple blocks ahead" of their students the whole year.

4.6.2. Social support for teachers

During the institute, the participants used language referring to themselves as an emergent collective. The teachers used the pronoun "we" frequently, referring to all institute participants, both facilitators and attendees. The two systems thinking researchers, Marisol and Abigail, confirmed this discourse, saying, "Systems thinking is about the collective learner." By the last day, new participants were talking about the work that had been done as a "collective conscious" and appreciating Stacy's presentation because of her emphasis on "the collective." They took up the language of the whole that emerged throughout the conference as they recognized they had more knowledge together than any one did alone. The teachers and consultants also made references to their classrooms as a "collective learner" and "collective consciousness"; additionally, several experienced teachers used "we" while describing the systems learning in their classrooms, including themselves in their classroom collectives.

Overall, teachers reacted to systems thinking not just as a pedagogy as practiced in this institute, but as an all-encompassing, holistic, theoretically-informed understanding of the world. Several teachers described systems thinking as being natural to the way they understood the world. Kelly concluded that "finding patterns" and "making connections" is what "our brains are eager" to do, and Chloe, a teacher new to systems, described systems thinking as "how [my] brain works." Denise agreed, explaining that systems thinking was "organic" to her because it was "how I see things."

Systems thinking pedagogy was a catalyst for teachers to consider the roles of their interests and preferences in their classrooms and with their teaching methods. Within the institute, the facilitators aimed to meet the attendees 'needs as learners, teachers, and theoretical thinkers; this understanding of teachers as having complex identities within the classroom was integral to systems thinking pedagogy.

4.7. Refocusing the purposes of education: Complexity and beauty

Systems thinking pedagogy focused on flexibility in teacher thinking. Binaries were discouraged and envisioning new ways of thinking was emphasized. The purpose of education turned toward seeing the possibilities. This is evident in the introduction of a broader way of thinking as well as turning toward the beautiful rather than building upon sorrow.

4.7.1. It's not "either/or"; it's "both/and"

The facilitation team selected the principle of "both/and" thinking (Cabrera & Colosi, 2009) as a goal for the institute. During the conference introduction, a member of the facilitating team explained that "both/and" thinking was a shift in typical thinking patterns: while people often think in terms of "either/or" and "but" when discussing seemingly opposing ideas, the facilitators wanted the attendees to use "both/and" instead. They further shared that using "both/and" represented a shift to make connections instead of separations between ideas. For example, an activity does not have to be fun *but* difficult; it can be *both* fun *and* difficult; the two ideas do not have to be exclusionary. To give the participants practice in shifting toward "both/and" thinking, the second day of the institute began with an activity about having a mindset of being "in," or being committed to the day's work. Everyone shared something that happened to them before

arriving at the institute that morning, and then followed the statement with "and I'm in." The example given was, "I stayed up late, so I'm tired…and I'm in." The activity highlighted that "both/and" thinking is not about a shift in situation but a shift in the way of thinking about situations as well as a commitment to embracing the philosophy in the institute.

The phrase "both/and" arose in multiple discussions throughout the four days, such as describing systems thinking as both "hard and beautiful at the same time." This combination revealed how teachers found systems thinking challenging to learn and teach while simultaneously recognizing way it nurtured their pedagogy. Systems thinking was also described as encouraging both "united" and "divergent" thinking because it provided a focus for everyone to share while stimulating individual thinkers to explore their own ideas. Additionally, the teachers recognized systems thinking to be both "simple" and "complex": simple in its focus and complex because "eventually everything connects."

The participants also used the notion of both/and thinking to understand how they found systems thinking to be a "natural" way of thinking and, at the same time, the thinking required a shift in their teaching practice. As the participants described systems thinking as "all around us," they also explained that applying it to teaching has "transformative power."

4.7.2. From "broken" to "beauty."

Beginning with the first group discussion, the term "broken" was often used when describing systems. Fixing "broken" systems aligned with the institute's emphasis on social justice and activism as an integral purpose (Tintiangco-Cubales et al., 2010) of systems thinking pedagogy. The facilitators all included culminating projects that required student action as a way to nurture agency in response to social inequalities or environmental issues. For example, Charlotte shared her use of the central question "How might [we] help fix an unfair immigration system?" in her third-grade classroom, particularly relevant to her students 'lives. The unit ended with the students writing letters about immigration laws to their political leaders, as well as designing informational brochures about resources for learning English to give to new neighborhood immigrants. Other facilitators gave examples of beach litter clean-ups and campaigning for local ecosystem preservation.

The potential of systems to be "broken" was one of the principles that the facilitators shared with the attendees, and "brokenness" was a principle that many of the experienced teachers described as emerging frequently in their classroom studies of systems. During the breakout sessions on the second and third days, multiple teachers described "broken systems" as the focus of their classroom systems studies. From the pollution system to the immigration system, all systems examples had elements of brokenness. Some teachers asserted that "fixing" broken systems was the reason to teach using systems thinking pedagogy.

The metaphorical shift away from "broken" as a key term happened in waves during the institute; it started with a few comments, built momentum, and became a shared value. The first disruption happened when a participant asked, "How do you define how a system is broken?" Maya, who had been serving as the map scribe for the discussion, offered an alternative: "Instead of saying broken, I say that systems can be interrupted or re-routed or out-of-balance." Later, Jacob, a participant who had just finished his first year of implementing systems thinking in his reading classroom, offered his thoughts: "I use the term 'systems malfunction' because it feels less linear than 'broken.'"

On the final morning, Stacy, who had been an early adopter of systems thinking at the host school, offered a counter vision of the purpose of systems thinking pedagogy. She explained that her systems thinking "story" leveraged the pedagogy as a way to have her students "connect to the beauty around them" in the natural world. While she agreed that addressing "brokenness" was critical, she argued that it was "imperative that students [connect with beauty] first," so they could understand their place in the world. She called for "a balance" of addressing both beauty and brokenness in systems thinking pedagogy. She argued that students 'need to "celebrate [the

world's] beauty every day" by going outdoors and integrating the natural world as part of the classroom.

Stacy's words brought the shift away from "brokenness" to an apex, provoking emotional responses in the attendees and facilitators. Maya choked up in the follow-up discussion when describing the times she and her students were "fearful" while studying the brokenness of systems and her desire for them to have the "hope" for beauty instead of fear. Over the course of the day, other teachers shared that they wanted to now "start with beauty" and "use that language [of beauty]" in their classrooms. Carmela, another facilitator, explained that Stacy's talk about "broken" systems made her realize she needed to include "happier" systems in her first-grade curriculum. Marisol, one of the systems thinking researchers who attended the institute, even named the notion of "going towards beauty" as one of her main takeaways from the institute. Seeing beauty became a purpose for systems thinking and a motivation for addressing brokenness. The attendees 'incorporation of the new perspective of "beauty" into their thinking captured the importance of having a flexible, inclusive mindset.

Overall, the discourse of the institute positioned systems thinking as a catalyst for pedagogical transformation. The participants used the language of movement and shifts as they constructed understandings about elements and principles of systems thinking. These systems thinking understandings built upon the foundation of the purpose of education (Tintiangco-Cubales et al., 2010): to understand and act upon the complexities of a world that is both beautiful and, at times, broken.

Most of those attendees who were newer to systems thinking quickly began to take up this perspective. The participants 'discourse emphasized the perceived transformation that understanding systems thinking theory seemed to require. They also used the discourse of systems thinking to understand the institute as an emerging collective, echoing the instructors 'descriptions of their classrooms as collectives.

5. Discussion

We drew on discourse within a four-day professional development institute to explore the construction and enactment of systems thinking pedagogy, and we showed in our findings that teachers were integrating systems thinking into their pedagogies and worldviews. In the institute, attendees and facilitators furthered their understanding of systems thinking and co-constructed a related discourse of systems thinking pedagogy.

Within the systems thinking pedagogy institute, the discourse included pivotal situated meanings of both pedagogy and systems thinking, including systems maps and principles. The participants "assembled" (Gee, 1999, p. 46-47) these situated meanings as they spoke, listened, and acted within the institute context. We addressed these assembled meanings of the pedagogy in the findings, including the purpose and methods of the pedagogy, important aspects of the identities of teachers and learners, and the context of learning (Tintiangco-Cubales et al., 2010).

Now we will draw on discourse theory (Gee, 1999) to consider the ramifications to the current educational models of teaching, learning, and teacher discourse. The participants 'discourse of systems thinking pedagogy challenged the prevailing cultural deficit models of teachers as incompetent instructors in need of scripted curriculum (Davis et al., 2015) and students as broken learners in need of interventions (Gay, 2010; Rodriguez, 2012). Instead, the participants 'cultural model of systems thinking pedagogy situated the identities of both teachers and students as capable academics. The model privileged a professional development culture of "becoming" where the power of the collective was a point of leverage (Meadows, 2008) for teachers to cultivate community and disrupt rigidity in what often counts as curriculum (Davis et al., 2015).

5.1. Privileging the Complex Identities of Teachers and Students

The discourse of systems thinking pedagogy situated teachers and students as capable academics, disrupting the cultural models (Gee, 1999) in Western education that posit deficit models (Gay,

2010; Rodriguez, 2012). Systems thinking pedagogy challenged the "habitualized actions" (Berger & Luckman, 1966, p. 71) of traditional classroom teaching in which teachers are experts who explain knowledge to learners, instead considering teachers to be co-learners who prompt students to build on knowledge and curiosities that they already have.

The discourse of the facilitators positioned teachers as capable by framing them as theorist-practitioners, meaning they drew from systems thinking theory to implement system thinking pedagogy. For example, the teachers developed their understanding of systems principles as they participated in the systems mapping activities. This view of "everyday people" having the ability to "form, transform, and deal with 'theories 'just as much as scientists" (Gee, 1999, p. 45) was seen in the institute's mapping sessions, where the systems principles emerged as "theories" from the group discussions.

The teachers formed theories about different systems, noticing and articulating systems principles just as they would ask students to do in the classroom. Positioning teachers as theorists who could deduce systems thinking principles without much prior understanding of systems theories recognized them as systems thinkers, and it also modeled for them how they should reconceptualize their students as active, agential learners. The participants 'discourse about teachers demonstrated a valuing of teachers 'abilities to develop high levels of systems thinking (Ben-Zvi Assaraf & Orion, 2005), that, once learned, can help to conceptualize how to address "wicked" problems (Cabrera & Cabrera, 2015). This discourse challenges the notion that professional development should primarily involve "practical" classroom strategies that merely link back to theory instead of enacting theory (Korthagen, 2017), suggesting instead that a balance of the practical and the theoretical is important, especially when asking teachers to change their classroom instruction—or their entire pedagogy. The participants 'discourse also considered teachers to be capable academics who could integrate systems thinking pedagogy with other pedagogies that aligned with its principles, including systemic sustainability education (Davis et al., 2015) and design thinking (Noel & Liub, 2017).

Interestingly, the reality of integrating systems thinking pedagogy into the current requirements of the educational system was not addressed with many specifics. Possible systemic barriers (McClure & Aldridge, 2022), like scripted curriculum ((MacGillivray et al., 2004; Rigell et al., 2022), regimented schedules (Oberle et al., 2021), and standardized tests (Eizadirad, 2019), were mentioned but not addressed in-depth (one breakout session that focused on standardized writing assessments was an exception), though they remain issues that most teachers will continue to face.

The participants' discourse also esteemed students as natural systems thinkers. It encouraged teachers to build on students' "natural" abilities to think about the world (Curwen et al., 2018; Koski & De Vries, 2013; Senge et al., 2000), instead of forcing them into a mechanistic worldview that attempts to explain the world by analyzing its parts (Capra & Luisi, 2014). The participants asserted their belief that, if students lack understanding of systems (Ben-Zvi Assaraf & Orion, 2010; Hmelo-Silver et al., 2007), it is not because they do not have the ability but because their inherent abilities to understand systems have gone unnurtured—or even squashed. From this perspective, beginning systems thinking pedagogy in primary schools is important not only because young students can develop systems thinking (Ben-Zvi Assaraf & Orion, 2010; Curwen et al., 2019; Danish et al., 2017) but because schools should foster students 'natural abilities and strengths to effectively improve learning (Galloway et al., 2020).

This study provided a view of both teachers and learners as capable academics who work as researchers and theorists, learning alongside one another. This reflects the findings in classroom studies on systems thinking pedagogy in which students and teachers worked together to understand and develop solutions to statewide drought (Curwen et al., 2018) and modern-day slavery (Curwen et al., 2019). Such collaborative learning is empowering for both teachers and students (Ardell & Curwen, 2019). Teachers and learners both were considered capable academics whose thinking added to the collective's growth.

5.2. Privileging the Language of "Becoming"

The "realized" world (Berger & Luckmann, 1966) of the institute was one of "becoming" a systems thinking teacher. The teachers 'language of shifting, moving, and transforming placed them in the process of change. While they had the words to explain their beginnings of "becoming" a systems thinking teacher, they did not use the language of "ending" or "arrival." The teacher's discourse suggested that the goal was not to reach an "end," but instead to make continual movement within becoming such a teacher.

Theorists and researchers "position the concept of becoming as an evolutionary, iterative process" that has been used to describe the complexities of learning to teach and also identifying as a teacher (Ovens, et al., 2016). "Becoming" a systems thinking teacher involves ways of talking and knowing that allowed teachers to be recognized by others as "systems thinking teachers." Such recognition did not require being finished with learning about systems thinking, but using specific concepts, language, objects, times, and places (Gee, 1999). The ways of identifying oneself as a systems thinking teacher included such activities as creating and posting systems maps and principles on the walls, spending class time in discussion about systems mapping, relating content across the curriculum, connecting places inside and outside the classroom, and asking open-ended questions, as well as theorizing about broken systems and beauty.

Another way that these teachers framed themselves as still "becoming" was in their use of language connected to the future (Gee, 1999). The teachers described using systems thinking pedagogy as having the potential to enact change both in classrooms, communities, and the world. The teachers, through talk of systems thinking and pedagogy, "built a future together" (Gergen, 1998) that focused on appreciating the world and using systems thinking to address its problems. This discourse reflects the temporal dimension of learning and "becoming" a teacher (Ovens, 2016).

This process toward "becoming" was both planned for and spontaneous during the institute, consistent with Davies and Harre (1990), "One lives one's life in terms of one's ongoingly produced self, whoever might be responsible for its production" (p. 49). For example, the institute's facilitators planned for the participants to begin shifting toward "both/and" thinking. However, this shift in emphasis from brokenness to beauty was spontaneous as both attendees and presenters responded enthusiastically to the words of Stacy, when she presented on her own classroom and evolution as a systems thinker.

Reflecting this quality of "becoming," the institute's systems thinking pedagogy was recursive and non-linear (Ovens, 2016), with learners returning continually to previous learning to reflect and revise (Davies & Harre, 1990). Current curriculum in school subjects is traditionally linear or spiral, focusing on movement toward new material and mastery of old material. In contrast, systems thinking pedagogy emphasized a continual recursive process of learning by regularly revisiting, revising, and re-learning "old learnings." Learning is never "finished," but is instead in a continual state of being increased, enhanced, and connected to other learning. This sense of "ever-becoming" was evidenced in the institute's plans to continue professional development with the attendees throughout the next school year (Ovens, 2016).

Important to this discourse of "becoming" was the framework of social constructionism on which the systems thinking pedagogy was built (Burr, 1995; Ovens, et al, 2016). We used social constructionist theory to consider how the pedagogy of systems thinking was communicated throughout the institute, looking at the purpose of activities and the order of the activities. We did not realize how much the consultants integrated constructionism and systems theories to create a pedagogy until we were analyzing the data. According to constructionist thought, to really know something means to be able to "recognize patterns…and act on" them "in a range of contexts" (Gee, 1999, p. 51). Instead of using direct instruction to move linearly through the curriculum, the institute facilitators designed the institute to have participants construct ideas from hearing stories, discussing ideas, making maps, finding patterns, generalizing principles, and reflecting together. The facilitators frequently rarely used direct instruction to teach systems thinking and its

principles because they wanted the teachers, like their students, to construct their understandings and "negotiate" meanings together. This combination of systems thinking with constructionism provided the basis for centralizing discussions and maps as the core activities of the pedagogy (Burr, 1995). The participants constructed (Berger & Luckmann, 1966) their systems thinking understandings and then applied them to their pedagogical understandings and beliefs, gaining skill in both areas simultaneously by tying assembled understandings to real situations (Gee, 1999).

5.3. Privileging Collectivity: Classrooms and Curriculum as Points of Leverage

The participants imagined several different collectives: the teachers in the institute, the teachers and students in a classroom, and the integrated curriculum. The power of these collectives was a point of leverage (Meadows, 2008) for teachers both to balance an educational culture that emphasizes individuality and to disrupt rigidity in what counts as curriculum. Acknowledging these collectives is a small change that has a potentially large impact in teaching and learning.

5.3.1. The collective learner: Power in combined strength

Throughout this professional development, the teachers were invited to share both their thoughts and feelings about systems thinking pedagogy; these times of reflection provided times to both share and create feelings of community (Goode et al., 2019). The interconnectedness of components is a key principle of systems thinking (Capra & Luisi, 2014), so developing it among the attendees reiterated the nature of systems thinking and reflected the pedagogy in the moment.

Working together, having discussions, and building on one another led to the emergence of a collective learner at the institute that mirrored what the experienced teachers had encountered in their own classrooms. In a time when the need to differentiate instruction is still a main focus in education (International Literacy Association, 2020), the teachers in the systems thinking institute recognized the power in developing the classroom collective learner while simultaneously providing "variable entry" points for diverse learners (Davis et al., 2015, p. 219).

This idea, on the surface, seems counterintuitive to the personalization of curriculum; however, the use of "both/and" thinking demonstrates that the two methods can coexist. Nurturing the development of the collective learner did not replace differentiated instruction; instead, it provided space for teachers to talk about bringing learners together in community while also meeting the needs of individual learners, decentralizing the teacher as the only source of knowledge (Castro, 2015). This recognition of the collective reflects the systems principles of relationship and synthesis (Capra & Luisi, 2014; Davis et al., 2015), which are a needed balance to the current educational principles of individuality, differentiation, and analysis (Bertram, 2012; Capra & Luisi, 2014; Davis et al., 2015). The teachers still considered students 'individual needs, and they shared ways in which systems thinking pedagogy had been both culturally relevant (Ladson-Billings, 1995) and inclusive of diverse learners (Curwen et al., 2019).

The teachers use used the idea of the collective as a point of leverage (Meadows, 2008) to balance individualization with the development of a community. The collective was composed of individual learners that became stronger together in dynamic conversation; such conversations can lead to increased effective practices within the classroom (Methlagl, 2022). In this case, it led to a shared confidence in choosing systems thinking pedagogy.

5.3.2. The integrated curriculum: Transdisciplinary power

The discourse of systems thinking pedagogy disrupted the rigidity in the current educational "cultural model" (Gee, 1999) of curriculum and replaced it with integrated, organic curricula developed by teachers alongside their students. This type of curriculum design is called collective curriculum, and it is a powerful form of praxis for developing learners 'participation in the learning process (Roth et al., 2012).

The teachers described a collective curriculum that was a holistic "transdisciplinarity" (Davis et al., 2015) instead of multiple, artificially separated subjects divided into discrete times of the day.

According to the participants, mapping organically allowed for discussion and the emergence of the systems principles, stressing the necessity of mental models (Hmelo-Silver et al., 2017; Senge et al., 2000) as conceptual representations of systems thinking and curriculum integration (Roth et al., 2012).

The consultants and experienced teachers employed open-ended questioning to address distinctions, systems of part-whole, relationships between ideas, and taking different perspectives (Cabrera & Cabrera, 2015) and to encourage deep thinking about complex topics (Ardell & Curwen, 2019). Posting the questions on the walls of the institute made them a part of the curriculum as much as the content knowledge on the maps and the systems thinking principles.

The inclusion of social justice (Curwen et al., 2018; Rong et al., 2014) as a part of the constructed pedagogy was evident in the ways the teachers enacted discourse (Gee, 1999) with the community. While social justice, environmental issues, and community involvement was a key purpose of the pedagogy according to the participants' discourse, it is a purpose not foregrounded in all studies of systems thinking in the classroom (for exceptions, see Ardell & Curwen, 2019; Curwen et al., 2019).

6. Implications and Conclusion

This study contributes to the field of professional development by highlighting the value of a teaching community. Additionally, there is power in having experienced teachers serve as facilitator as well as learning alongside attendees, as it emphasizes the importance of teacher leaders as "becoming" rather than just mastering material.

The transdisciplinary nature (Capra & Luisi, 2014; Davis et al., 2015) of systems thinking highlights the significance of integrating systems thinking across all subjects (Ardell & Curwen, 2019). However, is worth considering that this learning happened during the summer, when participants were not burdened by other obligations.

Overall, the participants' discourse about teaching and learning positioned systems thinking as a catalyst to transform many aspects of their pedagogy (Tintiangco-Cubales et al., 2010). The discourse integrated social construction and systems thinking into a cultural model of systems thinking pedagogy, and this pedagogical discourse disrupted the bigger "storyline" (Gee, 1999, p. 44) of Western education. Their constructed pedagogy shifted situated meanings around the complex identities of teachers and students and emphasized the importance of creating an emergent, integrated curriculum together. Additionally, their discourse cultivated professional development as a place for teachers to learn alongside each other as they developed a pedagogy that can help both them and their students prepare to face wicked problems while appreciating the beauty of life.

Author contribution: The second author supervised the first author in writing this article as part of a dissertation. Therefore, the first author is the main author while the second author is a contributor.

Declaration of interest: No conflict of interest is declared by the authors.

Ethics declaration: Authors declare that this study was approved by the Institutional Review Board at the University of Memphis on June 6, 2018 with reference number PRO-FY2018-670.

Funding: No funding source is reported for this study.

References

Ardell, A., & Curwen, M. (2019, April). *"It's good because it makes you change": Children's and teachers' responses to a curriculum grounded in systems thinking* [Paper presentation]. American Educational Research Association, Toronto, Canada.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report, 13*(4), 544-559. https://doi.org/10.46743/2160-3715/2008.1573

Ben-Zvi Assaraf, O., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Science Teaching, 42*(5), 518- 560. https://doi.org/10.1002/tea.20061

Ben-Zvi Assaraf, O., & Orion, N. (2010). Four case studies, six years later: Developing system thinking skills in junior high school and sustaining them over time. *Journal of Research in Science Teaching, 47*(10), 1253-1280. https://doi.org/10.1002/tea.20383

Berger, P., & Luckman. (1966). *The social construction of reality: A treatise in the sociology of knowledge.* Anchor Books.

Bertram, C.S. (2012). *Individualism in education reform* (Publication No. 1224048682) [Master or arts, Eastern Michigan University]. ProQuest Dissertations and Theses Global.

Bogard, T., Consalvo, A. L., & Worthy, J. (2018). Teaching for deep learning in a second grade literacy classroom. *Journal of Language and Literacy Education, 14*(1), 1- 26. http://hdl.handle.net/10950/2337

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77-101. https://doi.org/10.1191/1478088706qp063oa

Burr, V. (1995). *An introduction to social constructionism.* Routledge.

Cabrera, D., & Cabrera, L. (2015). *Systems thinking made simple: New hope for solving wicked problems* (2nd ed.). Plectica Publishing.

Cabrera, D., & Colosi, L. (2009). *Thinking at every desk: How four simple thinking skills will transform your teaching, classroom, school, and district.* Research Institute for Thinking in Education.

Capra, F., & Luisi, P.L. (2014). *The systems view of life: A unifying vision*. Cambridge University Press.

Castro, J.C. (2015). Visualizing the collective learner through decentralized networks. *International Journal of Education & the Arts, 16*(4). https://www.learntechlib.org/p/160127/

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis.* Sage.

Checkland, P. (1981). *Systems thinking, systems practice*. John Wiley & Sons.

Chen, R., Hughes, A.C., & Austin, J.P. (2017). The use of theory in family therapy research: Content analysis and update. *Journal of Marital and Family Therapy, 43*(3), 514-525. https://doi.org/10.1111/jmft.12217

Chinn, C.A. (2017). Commentary on promoting systems understanding. *Instructional Science 45*(1), 123-135. https://doi.org/10.1007/s11251-017-9406-4

Curwen, M.S., Ardell, A., & MacGillivray, L. (2019). Hopeful discourse: Elementary children's activist responses to modern-day slavery grounded in systems thinking. *Literacy Research: Theory, Method, and Practice, 68*(1), 139–161. https://doi.org/10.1177/2381336919870284

Curwen, M.S., Ardell, A., MacGillivray, L., & Lambert, R. (2018). Systems thinking in a second-grade classroom: Students engaged to address statewide drought. *Frontiers in Education, 3*, 90. https://doi.org/10.3389/feduc.2018.00090

Danish, J., Saleh, A., Andrade, A., & Bryan, B. (2017). Observing complex systems thinking in the zone of proximal development. *Instructional Science, 45*(1), 5-24. https://doi.org/10.1007/s11251-016-9391-z

Davies, B., & Harré, R. (1990). Positioning: The discursive production of selves. *Journal for the theory of social behaviour*, *20*(1), 43-63. https://doi.org/10.1111/j.1468-5914.1990.tb00174.x

Davies, B., & Harré, R. (2001). Positioning: The discursive production of selves. *Discourse theory and practice: A reader, 20*, 261. https://doi.org/10.1111/j.1468-5914.1990.tb00174.x

Davis, B., Sumara, D., & Luce-Kapler, R. (2015). *Engaging minds: Cultures of education and practices of teaching (3rd ed.).* Routledge.

DeMarrais, K. (2004). Qualitative interview studies: Learning through experience. In K. B. deMarrais & S. D. Lapan (Eds.), *Foundations for research methods of inquiry in education and the social sciences* (pp. 51-68). Lawrence Erlbaum Associates, Publishers.

Dyson, A. H., & Genishi, C. (2005). *On the case: Approaches to language and literacy research.* Teachers College Press.

Eizadirad, A. (2019). Decolonizing Educational Assessment models. In A. Eizadirad (Ed.), *Decolonizing Educational Assessment* (pp. 203–228). Springer. https://doi.org/10.1007/978-3-030-27462-7_10

Emerson, R.M., Fretz, R.I., & Shaw, L.L. (1995). In the field: Participating, observing, and jottingnotes. In R. M. Emerson (Ed.), *Writing ethnographic fieldnotes* (pp. 17-38). The University of Chicago Press.

Galloway, R., Reynolds, B., & Williamson, J. (2020). Strengths-based teaching and learning approaches for children: Perceptions and practices. *Journal of Pedagogical Research*, *4*(1), 31–45. https://doi.org/10.33902/jpr.2020058178

Gay, G. (2010). *Culturally responsive teaching: Theory, research, and practice (2nd ed.).* Teachers College Press.

Gee, J.P. (1999). An introduction to discourse analysis: Theory and method. Routledge.

Gergen, K.R. (1999). *An invitation to social construction.* Sage.

Gharajedaghi J. (2011). *Systems Thinking: Managing Chaos and Complexity* (3rd ed.). Elsevier.

Goode, G.S., Bailey-Tarbett, L.K., & MacGillivray, L. (2019, April). *"Pivoting toward the light": Addressing emotions in a systems thinking pedagogy professional development.* [Roundtable Session.] American Educational Research Association, Toronto, Canada.

Hmelo-Silver, C.E., Jordan, R., Eberbach, C., & Sinha, S. (2017). Systems learning with a conceptual representation: A quasi-experimental study. *Instructional Science, 45*(1), 53-72.https://doi.org/10.1007/s11251-016-9392-y

Hmelo-Silver, C.E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *Learning Sciences, 15*(1), 53-61. https://doi.org/10.1207/s15327809jls1501_7

Hmelo-Silver, C.E., Marathe, S., & Liu, L. (2007). Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *Journal of the Learning Sciences, 16*(3), 307-331. https://doi.org/10.1080/10508400701413401

Horton, M., Kohl, J., & Kohl, H.R. (1997). *The long haul: An autobiography.* Teachers College Press.

Hyerle, D. (2008). Thinking maps: Visual tools for activating habits of mind. In A. L. Costa & B. Kallick (Eds.), *Learning and leading with habits of mind: 16 essential characteristics for success* (pp. 149-174). Association for Supervision and Curriculum Development.

International Literacy Association. (2020). *What's hot in literacy report.* Newark, DE. https://www.literacyworldwide.org/get-resources/whats-hot-report

Ison, R.L. (2008). Systems thinking and practice for action research. In P.W. Reason & H. Bradbury (Eds.), *The Sage Handbook of Action Research Participative Inquiry and Practice* (2nd ed., pp. 139–158). Sage Publications.

Korthagen, F. (2017). Inconvenient truths about teacher learning: towards professional development 3.0. *Teachers and Teaching, 23*(4), 387-405. https://doi.org/10.1080/13540602.2016.1211523

Koski, M.I., & de Vries, M.J. (2013). An exploratory study on how primary pupils approach systems. *International Journal of Technology and Design Education, 23*(4), 835-848. https://doi.org/10.1007/s10798-013-9234-z

Kosko, K. W., & Herbst, P. (2012). A deeper look at how teachers say what they say: A quantitative modality analysis of teacher-to-teacher talk. *Teaching and Teacher Education, 28*(4), 589–598. https://doi.org/10.1016/j.tate.2011.11.010

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465-491. https://doi.org/10.3102/000283120320034

Lakoff, G. (1992). The contemporary theory of metaphor. In A. Ortony (Ed.) *Metaphor and thought* (2nd ed., pp. 202-251). Cambridge University Press.

Lakoff, G., & Johnson, M. (2008). *Metaphors we live by*. University of Chicago Press.

Leko, M. M., Kiely, M. T., Brownell, M. T., Osipova, A., Dingle, M. P., & Mundy, C. A. (2015). Understanding special educators' learning opportunities in collaborative groups: The role of discourse. *Teacher Education and Special Education, 38*(2), 138-157. https://doi.org/10.1177/0888406414557283

Liefshitz, I.A. (2015). *When teachers speak of teaching, what do they say? A portrait of teaching from the voices of the StoryCorps National Teachers Initiative.* [Doctoral dissertation, Harvard Graduate School of Education]. http://nrs.harvard.edu/urn-3:HUL.InstRepos:16461032

MacGillivray, L., Ardell, A. L., Curwen, M. S., & Palma, J. (2004). Colonized teachers: Examining the implementation of a scripted reading program. *Teaching Education*, *15*(2), 131–144. https://doi.org/10.1080/1047621042000213575

Madni, A.M., & Sievers, M. (2018). Model-based systems engineering: Motivation, current status, and research opportunities. *Systems Engineering, 21*(3), 172–190. https://doi.org/10.1002/sys.21438

Maturana, H.R., & Varela, F.J. (1987). *The tree of knowledge: The biological roots of human understanding.* Shambhala.

Meadows, D.H. (2008). *Thinking in systems: A primer.* Earthscan.

Methlagl, M. (2022). Patterns of teacher collaboration, professional development and teaching practices: A multiple correspondence analysis of Talis 2018. *International Journal of Educational Research Open*, *3*, 100137. https://doi.org/10.1016/j.ijedro.2022.100137

Miles, M.B., & Huberman, A.M. (1994). *Qualitative data analysis: An expanded sourcebook (2nd ed.).* Sage.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By State*s. The National Academies Press. https://www.nextgenscience.org/standards/standards

Noel, L.A. & Liub, T.L. (2017). Using design thinking to create a new education paradigm for elementary level children for higher student engagement and success. *Design and Technology Education: An International Journal, 22*(1), 1-12. https://doi.org/10.21606/drs.2016.200

Oberle, E., Zeni, M., Munday, F., & Brussoni, M. (2021). Support factors and barriers for outdoor learning in elementary schools: A systemic perspective. *American Journal of Health Education*, *52*(5), 251–265. https://doi.org/10.1080/19325037.2021.1955232

Ovens, A., Garbett, D., & Hutchinson, D. (2016). Becoming teacher: Exploring the transition fromstudent to teacher. In J. Loughran & M.L. Hamilton (Eds.), *International handbook of teacher education* (pp. 353-378). Springer.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4-15. https://doi.org/10.3102/0013189X029001004

Rigell, A., Banack, A., Maples, A., Laughter, J., Broemmel, A., Vines, N., & Jordan, J. (2022). Overwhelming whiteness: A critical analysis of race in a scripted reading curriculum. *Journal of Curriculum Studies*, 1–19. https://doi.org/10.1080/00220272.2022.2030803

Rong, L., Unger, L., & Scullion, V. (2014). Social justice through literacy: Integrating digital video cameras in reading summaries and responses. *Journal of Language and Literacy Education, 10*(2), 34-50. http://jolle.coe.uga.edu/wp-content/uploads/2015/04/Liu-Social-Justice-through-literacy.pdf

Rodriguez, V. (2012). The teaching brain and the end of the empty vessel. *Mind, Brain, & Education, 6*(4), 177-185. https://doi.org/10.1111/j.1751-228X.2012.01155.x

Roth, W.-M., Goulart, M. I., & Plakitsi, K. (2012). Engaging children in collective curriculum design. In W.-M. Roth, M. I. Goulart & K. Plakitsi (Eds.), *Science Education during Early Childhood* (pp. 67–90). https://doi.org/10.1007/978-94-007-5186-6_4

Saldaña, J. (2009). *The coding manual for qualitative researchers.* Sage.

Savin-Baden, M. and Major, C.H. (2013) *Qualitative research: The essential guide to theory and practice* (1st ed.). Routledge.

Senge, P.M., Cambron-McCabe, N., Lucas, T., Smith, B., Dutton, J., & Kleiner, A. (2000). *Schools that learn: A fifth discipline fieldbook for educators, parents, and everyone who cares about education.* Knopf Doubleday.

Soter, A.O. & Conners, S.P. (2017). Language as a field of energy: A critical question for language pedagogy. *Critical Questions in Education, 8*(1), 27-50.

Stull, A. T., & Mayer, R. E. (2007). Learning by doing versus learning by viewing: Three experimental comparisons of learner-generated versus author-provided graphic organizers. *Journal of Educational Psychology, 99*(4), 808–820. https://doi.org/10.1037/0022-0663.99.4.808

Tintiangco-Cubales, A., Kiang, P.N., & Museus, S.D. (2010). Praxis and power in the intersections of education. *AAPI Nexus: Policy, Practice, & Community, 8*(1), v-xvii. http://www.aapinexus.org/wp-content/uploads/2012/08/nexus8.1_ME.pdf

Webster-Wright, A. (2009). Reframing professional development through understanding authentic professional learning. *Review of Educational Research, 79*(2), 702-739. https://doi.org/10.3102/0034654308330970

Wilson, S. M. (2013). Professional development for science teachers. *Science, 340*, 310–313. https://doi.org/10.1126/science.1230725

Yin, R.K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.

Yoon, S.A., & Klopfer, E. (2006). Feedback (F) fueling adaptation (A) network growth (N) and self-organization (S): A complex systems design and evaluation approach to professional development. *Journal of Science Education and Technology, 15*(5-6), 353-366. https://doi.org/10.1007/s10956-006-9024-4

Yoon, S.A., & Hmelo-Silver, C. (2017). Introduction to special issue: Model and tools for systems learning and instruction. *Instructional Science, 45*(1), 1-4. http://dx.doi.org/10.1007%2Fs11251-017-9404-6

Yoon, S.A., Anderson, E., Koehler-Yom, J., Evans, C., Park, M., Sheldon, J., Schoenfeld, I, Wendel, D., Scheintaub, H., & Klopfer, E. (2017). Teaching about complex systems is no simple matter: Building effective professional development for computer-supported complex systems instruction. *Instructional Science, 45*(1), 99-121. https://doi.org/10.1007/s11251-016-9388-7

Appendix 1. The codes for each cycle are presented in alphabetical order; the exception is the final cycle, which is presented in the order used in the article findings. The first three cycles were conducted using all of the data. The two second cycles were conducted using all the first cycle codes. The final cycle "network centers" developed from mapping all codes

Cycle	Codes
First Cycle Initial Coding	access, across, active, address, adjust, affect, affirm, anxiety, ask, attention, awareness, balance, beauty, beginning, big(ger) picture, branching, brokenness, building, centering, challenging, changing, charts, choice, class, collaboration, collective knowledge, collective learner, community, comparing, complexity, components, connect, continual movement, continually revise, debate, decide, deepen, define, depth, design, develop, differentiate, direct, disagree, discuss, distinction, dualistic thinking, emerging, empathy, empowerment, encourage, end goals, enthusiasm, everything is connected, expanding, exploring, fearful, feelings, focus, framework, freedom, giving, going somewhere, grouping, grow, guiding, identities, inclusion, information, inspiration, interdisciplinary, inviting, life, listening, main ideas, making, mapping, mentor, metaphors, modeling, models, modifying, motivating, naming, narrowing, new, open-ended, organizing, ownership, parents, participation, partnerships, patterns, personal, positive, power, principles, problems and solutions, prompting, pushing, questioning, reading, reflecting, researchers, researching, retelling, revising, revisiting, scaffolding, seeing, self-assessment, sharing, shifting, social issues, standards, starting, strategies, stretched, students, successes, sustainability, synthesizing, systems, teachers, tensions, theory, thinking, time, transform, uncertain, uniting, universal, using, visuals, vocabulary, welcome, wholes, wondering, writing
First Cycle In Vivo Coding	"a chair can be a system," "a parent thanked me," "a world view," "act of writing makes it part of our curriculum," "affinity mapping is the 'so what'," "all systems are broken," "at first it gave me anxiety," "becoming aware of the impact of systems thinking," "being in the real world is in first grade," "brains are eager," "broadening and deepening as we move," "can we..," "center our room on broken systems," "children have always been systems thinkers," "collective consciousness," "connected to Earth," "couldn't shift my thinking"," "curriculum transformed," "debate happens," "deepens thinking as a learner," "different because of not knowing where it's going," "do more when working with other people," "does anything not have a purpose," "everyone contributes," "everything is a system," "everything's connected," "feel alive with systems thinking," "feels like my brain on a map," "go back to the principles," "go where the passion is," "hit a road block," "how do we handle issues," "how do we know it's enough," "I didn't know the students knew [that]," "I have so much to learn," "I pushed back," "I want my students to spread beauty," "I want to create little activists," "I'm in," "inspiring but exhausting," "is this going to work," "kids are alive and thinking," "learning is bigger and taller and deeper," "listen to students," "look forward in time," "make it more complex," "make positive change," "make them more discerning learners," "most alive I've been in a meeting in years," "my mind is exploding," "my systems journey," "need to learn to believe in teachers," "not yet, but I want to move toward that," "organic," "participating in democracy right now," "possible action is the reason for teaching systems," "principles are the syllabus," "put everything on the wall," "questions keep you alive," "right to learn this way," "social action," "starting at the beginning," "students are systems researchers," "systems can be interrupted and re-routed and out of balance," "take learning one layer up," "the smallest ideas connect to the largest," "transformative work," "trusting the process," "understanding deepens as we return," "want more about theory," "we were risk takers," "when everything is connected, everything matters," "you have to keep pushing"

Appendix 1 continued

Cycle	Codes
First Cycle Descriptive Coding	accommodate, accountability, action, assessment, attitude, beginnings, categorizing, collective knowledge, communication, community, complexity, concepts, connections, control, creativity, curriculum, deep learning, disagreeing, discussion, distinctions, drafting, emotions, environment, evolution, experiences, experimenting, finding gaps, generalizing, goals, history, interdisciplinary, interests, introduction, knowledge, language, leading, learning metaphors (i.e. organic, tall, wide), lifelong learning, macro systems, making decisions, mapping, micro systems, modify, motivation, nature, parts, pedagogy, personalizing systems, perspectives, principles, products, purpose, questioning, reading, real-world connections, relationship, research, restating, revisiting, self-efficacy, shifting, standards, systems, teacher qualities, teachers as learners, theme, theory, thinking, time, transformation, uncertainty, units, wholes, wisdom, wording, writing
Second Cycle Pattern Coding	biological systems language, collective learner language, curriculum language, emotional language, learning language, literacy language, movement language, research language, social systems language, student language, systems thinking language, teacher language, teaching language, theory language
Second Cycle Axial Coding	breadth of learning, classroom walls, classroom-world connection, depth of learning, emergence of collective, shift from "both/and" thinking to "either/or," shift from "broken systems" to "beauty," students as activists, systems as curriculum, systems maps, systems thinking as leverage, systems thinking as risk, teacher needs, teachers as learners, teachers as theorists, valuing students
Final Cycle "Network Centers"	Pedagogical transformation, Transforming the methods of teaching, Expanding the content of education, Enlarging the context of education, Revisioning ideas of who is being taught, Repositioning ideas of who is teaching, Refocusing the purposes of education